ACI News Letter

Vol. 22 No. 8 JOURNAL of the AMERICAN CONCRETE INSTITUTE April 1951

Efficiency Twins...

INTRUSION GROUT
PREPAKT CONCRETE

FOR

CONCRETE AND MASONRY REPAIRS • NEW CONCRETE CONSTRUCTION • BRIDGE PIERS • COFFERDAM SEALS • CAST-IN-PLACE PILES • CASING AND PROTECTION OF WOOD PILES • GROUTING • FOUNDATION STABILIZATION • UNDERPINNING • TUNNEL MAINTENANCE • DAMS • RETAINING WALLS • GROUTED CORE WALLS • EXPLORATION

Years of PREPAKT experience and careful job control assure you of the following qualities in PREPAKT CONCRETE:

- Any desired ultimate strength—1500 to 7000 p. s. i.
- No setting shrinkage and 50% less drying shrinkage.
- High permanent bond to existing concrete.
- Superior weather resistance, especially to cyclic freezing and thawing.
- Superior resistance to action of salt water.
- High impermeability to moisture.

PREPAKT, with all these favorable properties, requires 30% to 60% less portland cement than ordinary concrete of equal strength. PREPAKT may be made under water as well as in the dry, with equal facility and without increasing the cement content.

CONTRACTORS • ENGINEERS — PREPAKT — SPECIAL SERVICES

INTRUSION-PREPAKT, INC. THE PREPAKT CONCRETE CO.

CHICAGO • TORONTO **CLEVELAND 14, OHIO** SEATTLE • PHILADELPHIA

ZURICH - PARIS - MADRID - STOCKHOLM - HELSINKI - WIESBAD

ACI

News Letter Contents

April 1951

On the Cover—Using the vacuum process, it was possible to remove forms ½ hour after casting concrete pipe at Mucone, Italy. An impressive aisle is formed in the curing yard by the 16 ft long and 10 ft diameter pipe.

San Francisco meeting features varied program . 3

Steel savings seen in Code revision..... 4
Shotcreting standard adopted... 5
Convention approves higher dues 5
Quake resistant structures..... 6
Prestressing offers savings..... 8
Parking garage utilizes principle of toy blocks.....10
False set in cement can be corrected.....15
Construction costs cut with new materials.....18
Protection against atomic blast..20
Research.....24
Panel discussion.....25
Pacific Coast committee.....30
Committee meetings.....31
Three big entertainment features.33
Annual awards announced.....34

New officers elected.....35

Who's Who

Frank H. Jackson.....36
Committee 318.....36
H. Walter Hughes.....36

Positions and Projects—ACI Members.....37

Honor Roll.....44

New Members.....44

Synopses.....45

Discussion.....50

List of Advertisers.....50

San Francisco Meeting Features Varied Program

Atomic Blast Resistance
Earthquake Design
Building Code

ACI's 47th annual convention was its first, probably not last, on the Pacific Coast. For this memorable occasion, Feb. 20, 21 and 22, 571 registrants felt the warmth of San Francisco's special brand of hospitality—where California now has first rank in membership total.

The three-day program included sessions on structural design, materials and properties of concrete, construction, precast concrete, a panel discussion of concrete problems and the annual open session on concrete and cement research.

ACI technical committees presented one new standard and revisions of three others, all of which were passed by the convention and ratified by letter ballot of the membership.

A special session on precast concrete featured its use as protection against atomic blast. Advances in precast floor systems and structural elements were described, as well as construction techniques used.

Several design sessions had papers on concrete buildings to resist earthquakes, parking garages, arches, prestressed highway bridges and concrete pavements.

Construction topics included tilt-up techniques, lightweight monolithic construction, aggregate cooling plant for mass concrete, finishing and curing methods for improving concrete pavement durability and resurfacing concrete pavements with thin layers of concrete.

"False set" of cement, and concrete durability were discussed at a session on materials and properties. Other papers covered ultrasonic testing of concrete structures and studies of inhibitors of alkali-aggregate expansion.

Lighter portions of the convention program included the annual general luncheon and three entertainment features provided with the compliments of cement manufacturers, concrete and building industry, and engineers from the 11 Western states—a sightseeing trip through San Francisco's Chinatown, a dinner, and a twilight cruise on beautiful San Francisco Bay.

Steel savings seen in ACI Building Code revision

Revisions of the ACI Building Code approved at Tuesday morning's session and ratified by ACI members in letter ballot allow for improved properties of new-style deformed reinforcing bars, which saves steel in reinforced concrete construction. (See p. 589 for revised code.)

Can eliminate hooks

"If this type bar is used, we can eliminate hooks," stated Frank Kerekes, Chairman of Committee 318, Standard Building Code. "Eliminating hooks saves pounds of steel, which can be available for more civil or military use. In addition, we save man hours of labor and eliminate some difficult placing situations on construction jobs."

Increase bond stresses

The changes in "Building Code Requirements for Reinforced Concrete" decrease allowable bond stress in plain bars (including old types of deformed bars) and increase allowable bond stresses for new bar types over those allowed for the old types. Top bars, with more than 12 in. of concrete under them, are assigned lower bond stresses than bars in other positions.

In the new provisions, all plain bars must be hooked, to correspond with special anchorage under old provisions. The new reinforcing bars develop enough anchorage by bond alone to correspond to special anchorage with the old-type bars, *i.e.*, hooks are not necessary, resulting in less total steel required.

The new-style deformed reinforcing bars with higher, closely-spaced deformations have proved their superiority in bonding to concrete, in forming a series of narrow, closely-spaced cracks instead of a few wide ones, and in providing the equivalent of "special anchorage."

Bars in this country were originally plain round or square, then twisted square bars. It is only within recent years that the advantage of deformations on the bars themselves has been recognized. The majority of steel mills are now rolling only deformed bars that meet new ASTM specifications.

Several members of the West Coast convention committee relax and enjoy Western fellowship—(l. to r.) Chairman Harmer E. Davis, Institute of Transportation and Traffic Engineering, University of California; Wallace A. Marsh, Permanente Cement Co; Charles H. Purcell, California Highway Commission; and committee vice-chairman Robert Glenn, Institute of Transportation and Traffic Engineering.

Shotcreting standard adopted

Pneumatically placed mortar

"Recommended Practice for the Application of Mortar by Pneumatic Pressure," Committee 805, was adopted as a standard at the same session. (See ACI JOURNAL, Nov. 1950.) Revisions of two other standards were also adopted, and have now been ratified by ACI Members' letter ballots.

The new standard on pneumatically-placed mortar establishes recommended practices for placing and mixing shotcrete, qualifications and duties of workmen, preparation of surface before shotcreting, sequence of application, type and use of equipment and other items involved in shotcreting. The standard emphasizes the importance of workmanship in such construction.

Pavement specifications

"Specifications for Concrete Pavements and Bases," applying to construction of portland cement concrete pavement and base under normal conditions, including the preparation of the subgrade, was presented for revision by Committee 617.

New paragraphs include air entrainment, removal of forms, premolded joint fillers and joint filling materials and method of placing reinforcement. Definitions were added to the section on soil foundation preparation and other parts of this section were revised.

Several amendments were passed by the convention, in addition to revisions proposed in the Oct. 1950 JOURNAL, p. 93. These were the addition of ASTM Specification A 305 to the list of standards to which reinforcing bars must conform, and a change in lap requirements due to increased bond of new-style deformed bars.

Detailing manual

Revisions of the Institute's "Manual of Standard Practice for Detailing Reinforced Concrete Structures," Committee 315, make the manual conform with changes in ACI Building Code allowing new bond values for deformed reinforcing bars. (See ACI JOURNAL, Jan. 1951, p. 349.) Higher bond of the new bars eliminates need for hooks as anchorage when these bars are used. The bar designations in the manual were also changed to conform with numbered designation of the U. S. Department of Commerce Simplified Practice Recommendation R 26-50.

Chairman Raymond C. Reese, consulting engineer, Toledo, Ohio, said that in a survey of 146 technical institutions, 100 percent returns indicated various ways in which the manual could be used to advantage in teaching. Mr. Reese suggested that the next step in Committee 315 activity should be the preparation of a syllabus on using the manual as a teaching medium.

Convention approves higher dues

"For many years ACI has been spending a great deal more per capita than is received in dues. Last year that amounted to approximately $28 per member against national dues of $12.50 per member. That difference is made up by corporation contributions, margin in sale of reprints and advertising. But, in spite of that, it became evident that ACI was being forced to dig deeper into its reserve," stated Harry F. Thomson, chairman of the Board's Finance Committee, in introducing the proposal to raise membership dues.

He said the Board was faced with two alternatives: increase dues or drastically curtail services the Institute gives members.

The convention approved a change in the By-Laws which changed individual dues from $12.50 to $15, contributing member dues from $50 to $100, and corporation member dues from $25 to $50. Individual member dues for those not residing in North America* were raised from $10 to $12. There was no change in student or junior member dues. (See January NEWS LETTER for complete text.)

Changes in By-Laws have gone to all voting members of the Institute for ratification by letter ballot.

* Formerly this group excluded United States and Canada only. It has now been changed to North America, which includes all countries and territories in Central America and the West Indies. Authorities: *Commercial Atlas of America*, Rand McNally & Co., Chicago; and *Survey Atlas of the World*, The Times, London, England.

Concrete strength

The morning session concluded with a general summary of conditions affecting concrete strength by Walter H. Price, head, Materials Laboratory Section, Research and Geology Division, Bureau of Reclamation, Denver.

He discussed the effect of mix proportions, type and brand of cement, availability of moisture for curing, accelerators and curing temperatures on the rate and potential of strength development. The influence of rate and frequency of load applications, dimensions of test specimens and lateral restraint also effect the indicated strength.

"No matter how well a job is controlled there will be some variation in the strength," he stated. The number of values above and below the average fall into the familiar "bell-shaped" pattern. The better the control, the more values bunched close to the average, making for greater economy. (Published in ACI JOURNAL, Feb. 1951, p. 417.)

Reinforced concrete furnishes quake resistant structures

Earthquake resistant provisions of the San Francisco Building Code were met by the exclusive use of reinforced concrete in the construction of eleven 13-story apartment buildings at Parkmerced said John J. Gould, consulting engineer of San Francisco, at the design session, Tuesday afternoon.

The X-shaped apartments have flat-slab floors with wide flat beams over corridors. Exterior walls are of the bearing-wall type without columns. Many interior partitions commonly built of plaster or other materials are of reinforced concrete to resist vertical as well as horizontal loads.

"These provisions resulted in extremely economical structures," Mr. Gould said. Because of the structural system chosen, he estimated extra cost of earthquake resistance was only 1 to 2 percent of the total, as compared with otherwise sound minimum construction.

Major economies were realized, he continued, through elimination of plaster ceilings as concrete gave a pleasing finish. The structures were adapted for mass production and mass building methods—speed, simplicity of formwork, ease of placing and maintaining reinforcement, and speed and ease of placing concrete.

ACI's new president Harry Thomson enjoys a laugh at the Wednesday evening dinner

"A prime advantage of the interior bearing wall system is that lateral bracing is increased at no extra cost. A secondary advantage is that there are no breaks around columns in the rooms, thus giving more usable floor area." The foundations were tied together by a concrete slab and were generally individual footings. He went on to say that the interior bearing walls provide greater rigidity against vertical load deflections and greater safety to the occupants in case of earthquake or even atomic blast.

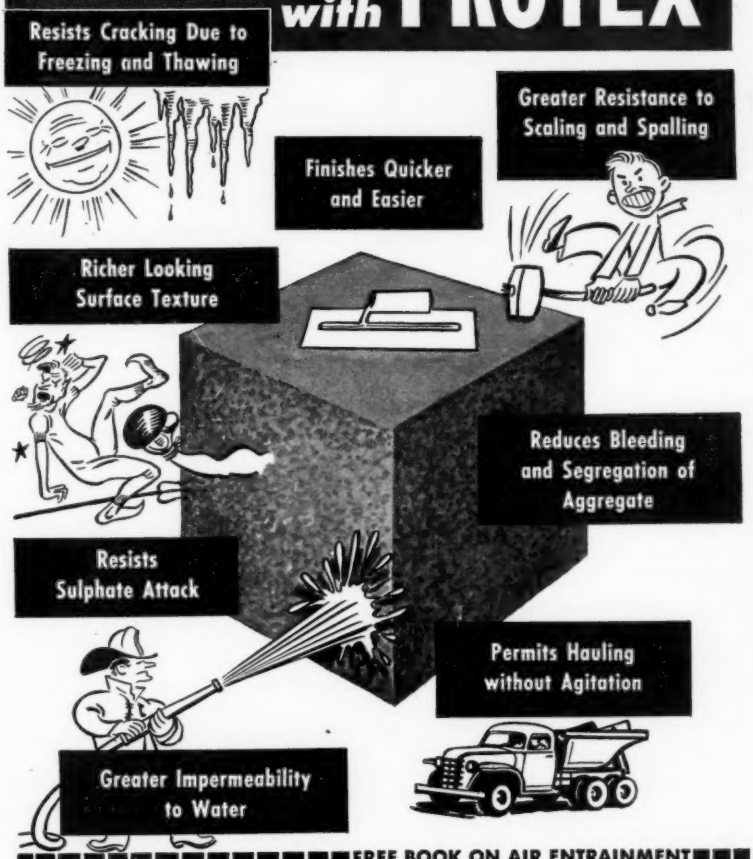
Reinforced concrete structures, properly engineered, afford effective protection against destructive forces of nature as well as atomic blasts asserted Mr. Gould. (Tentatively scheduled for June JOURNAL.)

Earthquake observations basis for rules

Other papers of the session were concerned also with earthquake resistance. Alfred L. Miller, University of Washington, Seattle, presented a paper by R. R. Martel, professor of structural engineering, California Institute of Technology, Pasadena, discussing earthquake resistance as learned from observations of earthquake damage.

Some general rules of thumb derive from observations of earthquake damage, he said, but these are not enough in not being quantitative. "There are so many variables: building layout, materials, workmanship, founda-

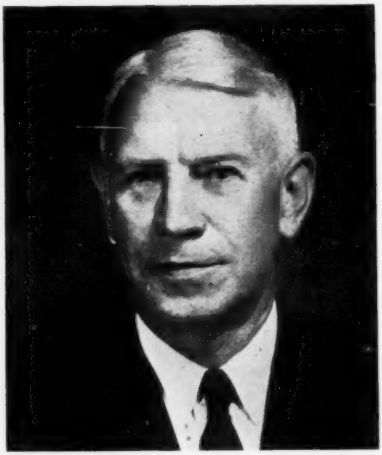
Get ALL the Advantages of Air-entraining *with* PROTEX


Resists Cracking Due to Freezing and Thawing
Greater Resistance to Scaling and Spalling
Finishes Quicker and Easier
Richer Looking Surface Texture
Reduces Bleeding and Segregation of Aggregate
Resists Sulphate Attack
Permits Hauling without Agitation
Greater Impermeability to Water

FREE BOOK ON AIR ENTRAINMENT

FOR LOWER FINISHED COST PER YARD OF CONCRETE . . . USE **PROTEX**

AUTOLENE LUBRICANTS CO.
Industrial & Research Division, Denver 9, Colorado
Please send me your book, "Facts on Modern Placement of Concrete Through Air Entrainment."
*Name*_____
*Address*_____



Frank E. Richart, research professor of engineering materials, University of Illinois, long active in Institute affairs, was elected to Honorary Membership.

tion conditions, as well as varying combinations of earthquake forces and character, that damage data can often be interpreted convincingly in different ways." (Tentatively scheduled for June JOURNAL.)

New design method

A paper by Charles S. Whitney, Boyd G. Anderson and Mario G. Salvadori, of Ammann and Whitney, consulting engineers, New York, explained a new method for the design of structures under dynamic loading which is applicable to earthquake design. This step-by-step analysis of earthquake stresses takes into account the stiffness of the structure, rocking of the foundation due to the elasticity of the ground, and period and amplitude of earthquake components. (Tentatively scheduled for June JOURNAL.)

H. J. Brunnier, consulting engineer, San Francisco, admitted that engineers still have problems in designing against earthquakes because their exact behavior is not known, nor is the exact behavior of buildings known. The principal thing, he said, is that lateral stability must be considered in design.

Discard the crystal ball

"The only way to find out about an earthquake is to have one, discard the mystical and mathematical, and give a practical interpretation of what happened," asserted Professor Miller, in discussing earthquake effects. He stated that most structures that fail are essentially piles of material not fastened together; such failure can be avoided if these piles are tied together.

He reviewed briefly the work of the Seismological Field Survey of the Coast and Geodetic Survey, and the newly organized Earthquake Engineering Research Institute.

Prestressing offers savings in freeway construction

Prestressed slab construction offers particular advantages for urban expressways and freeway separations where shallow depths are pertinent, said Stewart Mitchell, bridge engineer, California Division of Highways, Sacramento, at the Tuesday afternoon session. Although, at present labor costs, prestressed construction offers little saving over ordinary types of construction, if and when the prestressing cost is reduced it will compete with conventional construction, he predicted.

Considerable savings would be possible in depressed freeways and grade separations, Mr. Mitchell believed, because of reduced cost of the bridge superstructure and reduced excavation. Since prestressing allows less depth of beam, the reduced depth of overpasses would save substantial quantities of excavation as well as allow savings in cost of abutments, retaining walls, etc.

The use of prestressing will increase the economical span lengths of concrete slabs and girders and will make this type of construction competitive in span lengths formerly reserved for concrete arches and steel structures, he declared.

But, he asserted, prestressed bridge construction will be accelerated in the United States only "when American engineers take their eyes from the practices favored in Europe and develop fabrication and erection methods suited to American conditions."

It was noted that prestressing may be warranted even where no actual monetary saving over conventional reinforced concrete

FIRM ANCHORAGE... PLUS NEW-BILLET STEEL

You get two important advantages when you use the improved Bethlehem Reinforcing Bar: (1) firm anchorage in concrete, and (2) a bar that's made from new-billet steel.

The Bethlehem Reinforcing Bar has specially designed lugs which meet the deformation requirements of ASTM Specification A305. These lugs are alternately sloped and uniformly spaced. They provide adequate gripping action in the concrete. They minimize slippage at working loads. They help prevent the formation of wide tensile cracks in the concrete.

The improved Bethlehem Reinforcing Bar is high in quality and uniform in strength because it is made from new-billet steel which meets ASTM Specification A-15. In conformance with Simplified Practice Recommendation R26-50 of the U. S. Dept. of Commerce, the bar is rolled as a round section, with the size designated by a number, which is branded at regular intervals on each bar.

As no change has been made in either the standard unit weights or nominal cross-sectional areas of the Bethlehem Bar, there is no need for you to alter basic design practices. See the table below for the new bar numbers, old size designations, nominal areas and diameters.

To make it easy for you to refer to this essential data about the Bethlehem Bar, we have prepared Descriptive Sheet 138. For your copy, get in touch with us at Bethlehem, Pa.

BETHLEHEM REINFORCING BAR DATA

New Bar No.	2	3	4	5	6	7	8	9	10	11
Old Size	¼ in. Round	⅜ in. Round	½ in. Round	⅝ in. Round	¾ in. Round	⅞ in. Round	1 in. Round	1 in. sq.equiv.	1⅛ in. sq.equiv.	1¼ in. sq.equiv.
Nominal Area (sq. in.)	.05	.11	.20	.31	.44	.60	.79	1.00	1.27	1.56
Nominal Diam.	.250	.375	.500	.625	.750	.875	1.000	1.128	1.270	1.410

BETHLEHEM STEEL

BETHLEHEM STEEL COMPANY, BETHLEHEM, PA.

On the Pacific Coast Bethlehem products are sold by Bethlehem Pacific Coast Steel Corporation. *Export Distributor:* Bethlehem Steel Export Corporation

Bethlehem Reinforcing Bars

Where did they hail from?

The West Coast, Midwest and East Coast, as well as Canada, England and Mexico, were represented in the 571 registrants at the San Francisco meeting.

Calif.	392	Ohio	4
Wash.	17	Miss.	3
Ill.	17	Nev.	3
Canada	14	Mexico	3
Colo.	14	Kan.	2
N. Y.	14	Mo.	2
District of Columbia	13	Mont.	2
		N. J.	2
Ore.	11	Del.	1
Wis.	9	Fla.	1
Idaho	7	La.	1
Mich.	7	N. C.	1
Ia.	6	N. M.	1
Texas	6	Pa.	1
Ind.	5	Utah	1
Minn.	5	W. Va.	1
Mass.	4	England	1

is realized because of possible savings in concrete and steel. "It has been demonstrated that prestressed construction permits saving as much as 50 percent in quantity of concrete and 80 percent in poundage of steel." (Tentatively scheduled for June JOURNAL.)

Prevention of joint trouble

F. N. Hveem, construction engineer, also with the California Division of Highways, discussed at the same session, prevention of joint trouble in concrete pavements. He reported warping and curling of slabs a major factor in pumping and faulting of joints. A suggested remedy was elimination of expansion joints and placing contraction joints as far apart as possible. The effects of pumping can be counteracted or reduced by treating the subgrade with either asphalt or cement so that it will not be eroded readily by slab movement under traffic. (Tentatively scheduled for June JOURNAL.)

Parking garage utilizes principle of toy blocks

The principle of unit buildings, an arrangement of identical parts so that the completed structure is composed of a repetition of like units, as with toy blocks, was used in the construction of a New Orleans parking garage described by L. G. Farrant and W. C. Harry, consulting engineers, Miami, at the Wednesday morning session. The 30 units used in the parking garage resembled a set of tables resting on each other.

An ideal balance between function, economy and aesthetic value were achieved, the authors said, in unit buildings and flat-slab construction.

The flat slab allowed space for parking as well as horizontal movement of cars. A ramp was supported between building units for access to the parking space. Since the units could be separated, both horizontal and vertical movement was provided without complicating the structure. An extra row of cars can be accommodated since cantilevers were overlapped at the center of the building. Since the cantilevers would develop large moments in columns, a tapered column hinged at the base was used to eliminate need for large supports, since it reduced the moment in columns and maintained the nature of the unit structure. The column also provided a maximum parking area at the tapered base.

Garage cost was $400 per car exclusive of property values, Mr. Farrant declared — this below the national average. The yardstick provided by the American Automobile Assn. calls a garage economically sound if the cost is no more than $1350 per car. This economy resulted partly from its open decks, eliminating need for walls and mechanical ventilation.

The slab was reduced to 7½ in. instead of the 12 in. needed if the garage had been designated as a continuous monolithic structure.

Construction economy was possible in that concrete need not be placed continuously, but carried from one unit to another and one slab to another. As units are similar there was maximum standardization and reuse of forms. Savings in steel were accomplished with new-style high-bond reinforcing bars eliminating hooks and reducing anchorage requirements. (Tentatively scheduled for May JOURNAL.)

Slab system for roofs

The morning session on design included also a paper, "Getting More for Our Concrete Dollar," by I. E. Morris, consulting engineer, Atlanta, Ga., presented by Frank Kerekes, Iowa State College, Ames, describing a slab

REX PUMPCRETE®

YOUR AUTOMATIC INSPECTOR OF CONCRETE QUALITY

Rex Pumpcrete . . . *the pump that pumps concrete through a pipe line* . . . is an *automatic inspector* that inspects the quality of every batch of concrete pumped to the forms.

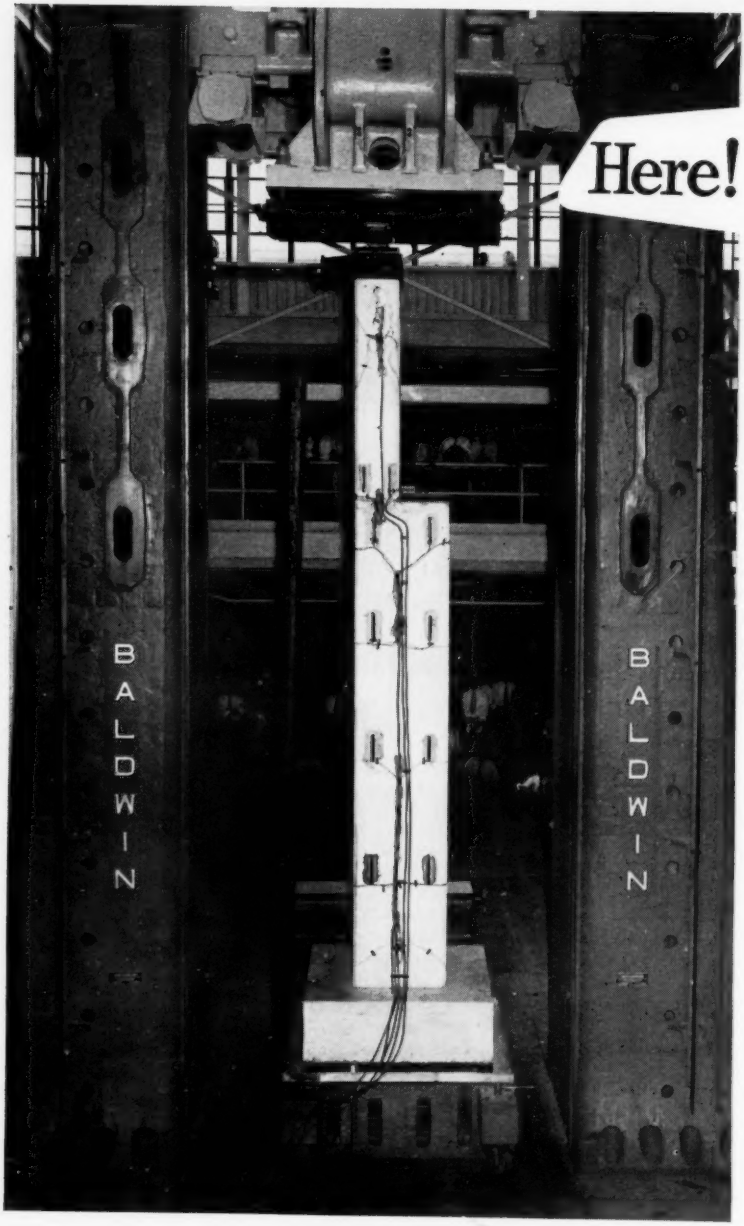
FIRST. Where segregation of the batch has occurred through mishandling or unsatisfactory mixing, the remixing hopper of the Pumpcrete will automatically correct this condition, assuring highest quality concrete.

SECOND. When the batch contains inferior aggregates, or is a poor mix, the Pumpcrete will refuse to pump it! It *automatically* inspects batch quality!

THIRD. The piston and valves of the Pumpcrete form the plastic concrete into cylinders which are placed in the sealed pipe line and pumped directly to the forms. There is no chance for segregation of the concrete during travel through the *sealed* pipe line. Concrete arrives at the forms in the same unsegregated, high quality condition as it was when it entered the pipe line.

For highest quality concrete . . . for automatic inspection of concrete quality, rely on Rex Pumpcrete. For the complete story, write Chain Belt Company, 1713 W. Bruce Street, Milwaukee 4, Wis.

CHAIN BELT REX COMPANY — CONSTRUCTION MACHINERY

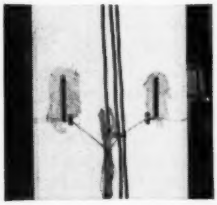

Here!
BALDWIN
BALDWIN

THE BIGGEST AND THE SMALLEST

BALDWIN TESTING DEVICES

TEAM UP TO TELL MORE ABOUT CONCRETE

The 5,000,000 pound push available in this Baldwin Universal Testing Machine at the Bureau of Reclamation Laboratory, Denver, is helping to "squeeze" additional information out of *full-scale* concrete members and structures, expanding the pool of engineering knowledge in the concrete design field. Here, a 22-foot high reinforced concrete step column is being tested in compression. Failure of the upper portion occurred at a total load of 1,675,000.



SR-4 GAGES® REVEAL STRESS PATTERNS

Another Baldwin Testing device . . . the SR-4 strain gage . . . extends the design-benefits of the test. During the entire duration of load application, these SR-4 gages, mounted both externally and internally, telegraphed dozens of local stress-strain stories to a central recording station. Result . . . a complete picture of the stress pattern in the column and invaluable data for design-improvements of concrete structural members and assemblies.

You will find Baldwin Concrete Testing Machines helpful aids in plant, highway and construction laboratories for routine and specification testing. For further information on the advantages of these Concrete Testing Machines you are invited to write for the following bulletins:

Bulletin 327—on the Baldwin 100,000 lb. Concrete Testing Machine
Bulletin 318—on the Baldwin 300,000 lb. Concrete Testing Machine

BALDWIN-LIMA-HAMILTON CORPORATION—Philadelphia 42, Pa., U. S. A.
Offices: Chicago, Cleveland, Houston, New York, Philadelphia, Pittsburgh, San Francisco, St. Louis, Washington. *In Canada:* Peacock Bros., Ltd., Montreal

BALDWIN-LIMA-HAMILTON

TESTING HEADQUARTERS

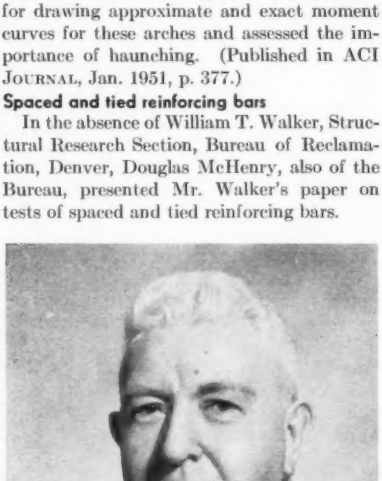
system of framing intended primarily for roofs where an exposed ceiling is desired for economy. The slab has alternating horizontal elements connected by sloping elements, which Mr. Morris said utilized concrete and steel to maximum advantage and at the same time had enough effective depth to span a reasonable distance without excessive deflection. In commenting on the design of concrete slabs he said that all structural concrete in a member should be put to work. (Published in ACI JOURNAL, Jan. 1951, p. 389.)

Arches

The effects of lateral loads on arches and the magnitude of these effects were considered by James P. Michalos, associate professor of civil engineering, Iowa State College, Ames. He discussed the effects of wind on unbraced arch ribs and arch ribs braced with struts normal to the ribs. He presented procedures for drawing approximate and exact moment curves for these arches and assessed the importance of haunching. (Published in ACI JOURNAL, Jan. 1951, p. 377.)

Spaced and tied reinforcing bars

In the absence of William T. Walker, Structural Research Section, Bureau of Reclamation, Denver, Douglas McHenry, also of the Bureau, presented Mr. Walker's paper on tests of spaced and tied reinforcing bars.



Harrison F. Gonnerman, assistant to the vice-president for research and development, Portland Cement Assn., elected to Honorary Membership, has been an ACI Member since 1918.

Beam and pull-out tests at the Bureau indicated that little or no advantage was obtained by spacing deformed reinforcing bars at splices. In pull-out tests, when deformed bars were placed vertically, with interlocking of lugs, there was a slight increase in strength due to tying the bars, while beam tests showed no significant difference between spacing and tying. (Published in ACI JOURNAL, Jan. 1951, p. 365.)

F. N. Menefee, University of Michigan, Ann Arbor, commented that these tests and others had shown need for revision of ACI's Building Code in relation to spacing reinforcing bars, especially in precast joists. He mentioned the work of Committee 711, Precast Floor Systems for Houses, in this respect.

The bundling of reinforcing bars was discussed and H. M. Hadley, consulting engineer, Seattle, concluded that in many instances it can be done with safety to the structure. He made the plea that many rules should be revised to conform with the reality of nature.

J. P. Thompson, Portland Cement Assn., Chicago, secretary of the Building Code committee, said the group was working on a section on precast concrete to be included in the Code that would eventually take care of many of the objections raised by building inspectors on such projects, since the Code was evolved principally for monolithic and cast-in-place construction.

Proper design lowers cost

An added bonus in the morning program was an illustrated talk by R. C. Sandberg, architectural engineer, Rock Island, Ill., who emphasized that structural and architectural design cannot be separated. Good structural design is also pleasing in appearance. Costs can be lowered through proper design so that the structure itself offers acoustical properties without extra materials. The projects illustrated used precast concrete elements to good advantage; and showed how the structural frame and its elements gave finished interior and exterior surfaces without added architectural treatment.

By following these principles, it was possible to build one school building at a cost of about $11,000 per classroom. In a church with precast arches, the entire structural design became the architectural design of interior as well as exterior.

False set in cement can be corrected in manufacture

Most cases of false set in cement can be corrected in manufacturing, according to R. F. Blanks and J. L. Gilliland, chief, Research and Geology Division, and head, Chemical and Cement Laboratoy, respectively, Bureau of Reclamation, Denver, at the Wednesday morning session on materials and properties.

The authors reported several ways to overcome false set (often called rubber set or gum set). Holding down grinding temperatures by using cool clinker and water-sprays on the mills has been very successful, and wherever proper precautions to cool the mills have been taken, false set has disappeared. The authors found it generally agreed that premature stiffening usually stems from unstable gypsum (plaster set) and the most common cause of unstable gypsum in cement is a high grinding temperature. Instability is also affected by storage temperatures, aeration and moisture.

Another possible approach, they said, is to use stable calcium sulfate, either natural anhydrite or gypsum which has been calcined to form insoluble anhydrite. Limited tests have shown that low alumina cements may be adequately regulated with these materials.

In some cases the addition of an admixture at the mixer has relieved false set in cement. Mechanically, stiffening can sometimes be overcome by prolonged mixing, or by remixing. This "doctoring" is not as desirable as a change in the manufacturing conditions responsible for false set.

"When stiffening of concrete occurs, it delays construction schedules,, causes excessive bleeding, makes uniform control of concrete quality practically impossible, and increases the cost of handling, placing and finishing."

"Certainly the problem is worthy of the research necessary to provide a solution that will be satisfactory to both consumer and producer," the authors concluded. (Published in ACI JOURNAL, Mar. 1951, p. 517.)

"There is no question that dehydrated gypsum is one of the reasons for false set, but not the only one," declared Myron A. Swayze, Lone Star Cement Corp., New York, in discussion. Grinding temperatures can be controlled, but many factors contributing to false set are beyond control of the cement plant.

Coarse-ground cement

Cement was also discussed by H. W. Brewer and R. W. Burrows, Bureau of Reclamation, Denver, who reported tests showing that coarse-ground cement produces more durable concrete than fine-ground cement. They concluded from these tests that concrete made with coarse-ground cement is more resistant to cracks resulting from drying and that it has a greater resistance to freezing and thawing under normal exposure. (Published in ACI JOURNAL, Jan. 1951, p. 353.)

Hubert Woods, Portland Cement Assn., Chicago, said that the way to frost-resistant concrete does not lie in the use of coarse-ground cement, but in the correct use of air entrainment. He stated that entrained air will not always prevent deterioraton of concrete subjected to freezing and thawing, however, "frost resistant concrete cannot be expected to result from manipulation of cement fineness."

Tests made at the PCA laboratories were cited to show "that there is no general relation

Elected ACI vice-president for a two-year term, Henry L. Kennedy, Dewey and Almy Chemical Co., joined the Institute in 1934 and has been active in technical committees and on the Board, 1944-49.

which can be given any degree of generality between the fineness and durability because the whole thing seems to be determined by the way in which the experiments are made."

In answer, Mr. Burrows emphasized that air entrainment was not the whole solution to deterioration. "The wetting and drying, heating and cooling cycles can eventually weaken a concrete so it is not protected from freezing and thawing, even with entrainment of air. Coarse-ground cement reduces shrinkage and cracking while air entrainment has little effect upon this common weakness of concrete."

He explained that contradictory data often result from test procedures where short drying periods, after initial thawing, are used.

Winter curing simplified

Mr. Brewer with J. J. Shideler and Wilbur H. Chamberlin, also with the Bureau of Reclamation, presented another paper showing that entrained air simplified winter curing. These tests indicated that less protection against freezing during curing is required when air-entraining concrete is used. (Published in ACI JOURNAL, Feb. 1951, p. 449.)

"This reduced period of protection, coinciding with the greatest heat evolution, makes insulation practical as a means of winter protection," noted L. H. Tuthill, also with the Bureau. He mentioned a project in northern New Mexico where 1-in. insulating blankets, Rockwool between Sisalkraft paper, were used successfully. The temperature under the mat was 20 to 40 degrees above outside temperature.

At another dam, steel forms were insulated by filling the ribs in the forms with sawdust and putting an outside sheet on them. The wooden forms in power house walls were readily insulated by filling between studs with sawdust or shaver plannings and dumping 8 in. of sawdust on the walls.

"The heat is in the concrete. We can use that to advantage in winter protection," Mr. Tuthill declared.

Soniscope used effectively

Use of the Soniscope in determining the condition of structures was described in the paper by E. A. Whitehurst, research engineer, Joint Highway Research Project, Purdue University, Lafayette, Ind., and presented by I. L. Tyler, Portland Cement Assn., Chicago.

He reported that the Soniscope, which measures group velocities through as much as 50 ft of concrete, was used to field test various types of structures. Repeated tests permitted study of changes in the condition of the concrete and the development of group velocities indicating the condition of the structure.

"The more complete the knowledge of concrete mix proportions, aggregates, methods of placing, etc., the greater the assurance which may be placed upon the interpretation of group velocity measurements." (Published in ACI JOURNAL, Feb. 1951, p. 433.)

Alkali-aggregate expansion inhibitors

The morning program also included a paper on alkali-aggregate expansion inhibitors by W. J. McCoy and A. G. Caldwell, director of research and research chemical engineer, respectively, Lehigh Portland Cement Co., Allentown, Pa.

Experimental data were reported which indicated that small amounts (1 percent or less) of specific salts added to high alkali cement are effective in reducing expansion. Other tests showed that 0.2 percent or less of selected proteins appear to inhibit expansion to a greater degree than comparable air entrainment introduced by conventional air-entraining agents.

The materials which appear to be the most effective in reducing expansion are copper sulfate, lithium salts, and air-entraining substances such as aluminum powder, various proteins and proprietary agents.

"It may be that these materials are too expensive for practical use in concrete," they stated, but the research conducted has offered another approach to the problem of reducing expansion due to alkali-aggregate reaction. (Tentatively scheduled for May JOURNAL.)

The JOURNAL is indebted to Turner Barton, advertising manager, Permanente Cement Co., Oakland, Calif., and William Q. Hull, associate editor, Chemical and Engineering News, San Francisco, for the convention photos.—Editor.

Darex AEA

is a catalyzed air entraining agent, *specifically formulated* for making air entrained concrete.

Darex AEA

is being used in all types of concrete work, all over the world.
Distribution warehouse stocks are conveniently located throughout North and South America and in most foreign countries.

One of four flood control projects in Kansas' Verdigris River Valley, the Fall River dam was constructed with DAREX AEA concrete because of its reduced bleeding and segregation, its better workability without the use of excess water.

DEWEY AND ALMY CHEMICAL COMPANY
CAMBRIDGE 40, MASSACHUSETTS
CHICAGO. 38 MONTREAL 32

DAREX REG. U. S. PAT OFF

Construction costs cut with new materials

"Rising costs of labor and materials have made it imperative for architects and structural engineers to work more closely together—the structural engineer to devise new methods of framing, the use of new materials, and the architect to adapt his design concepts to their best use," declared J. A. Murlin, of George L. Dahl, architectural and engineering firm, Dallas, Texas, at the construction session Wednesday.

"Now that we are faced with a short-of-war emergency, it is all the more important that we learn to use noncritical materials, and still keep down the over-all cost," he asserted.

In describing lightweight concrete construction, Mr. Murlin illustrated the potentialities of new materials in reducing structural costs. He did not evaluate the attendant savings effected in heating, lighting and plumbing when lightweight materials are used.

Although lightweight concrete can be substituted for ordinary concrete in almost any type of framing, to achieve the greatest economy it should be used only where it makes the most effective contribution.

If steel is the critical item on a project, it is possible to save steel by increasing floor slab thicknesses with lightweight concrete, although the increased depth will make costs equal or exceed costs of sand-gravel concrete. He emphasized that one of the advantages of lightweight concrete was that it permits use of flat plate type of construction with much greater column spacing than is economical with ordinary concrete.

Precast lightweight concrete floor and roof joists also offer savings in framing costs. Mr. Murlin said that on a Dallas school building the saving amounted to almost a dollar per sq ft in favor of lightweight, precast joists. (Tentatively scheduled for September JOURNAL.)

Key to durable pavements

The afternoon meeting also included papers on finishing and curing, resurfacing concrete pavements, architectural concrete, and the aggregate cooling plant for mass concrete at Detroit Dam.

Myron A. Swayze, director of research, Lone Star Cement Corp., New York, said that finishing and curing methods offered the key to durable concrete pavement surfaces. He recommended that finishing operations be delayed until the concrete is close to its initial set and should be preceded by compaction of the upper portion of the slab. "Nearly all finishing of concrete surfaces today is performed too soon."

Mr. Swayze also suggested that early application of curing water is wrong, that it should not be added until the concrete has reached its maximum temperature and is beginning to cool. However, the protection of the surface from evaporation and from carbonation by contact with the air is essential. (Published in ACI JOURNAL, Dec. 1950, p. 317.)

T. C. Powers, Portland Cement Assn., Chicago, augmented Mr. Swayze's paper by saying that half measures will not do and that a critical re-evaluation of current practices is warranted. "Beginning and ending the finishing process too soon can produce a slab that will scale under frost action."

The importance of properly managing the finishing and curing schedule is important in considering capillary forces, as well as mechanical compaction, he declared. "The control of capillary forces is as subject to abuse as the application of ordinary tools in finishing and curing."

Resurfacing pavements

H. Walter Hughes, associate engineer, Department of Public Works, Rochester, N. Y., described resurfacing of concrete road slabs with thin layers of concrete. Results indicated that the use of low water-cement ratio, graded mixes and compaction gives ample bond for thin toppings of badly scaled pavements in which the concrete is sound.

"Experience has shown that dense, weather-resistant concrete surfaces can be produced by using dry, harsh mixtures, finished with a compactor power float." (See p. 653, this issue.)

An architect's viewpoint

The program also included a discussion by Michael Goodman, professor of architecture, University of California, Berkeley, "An Architect Looks at Concrete."

The

KELLEY COMPACTOR POWER FLOAT*

for

Surfacing, compacting, densifying and finishing concrete wearing surfaces

The weight of the machine, plus the action of the compacting hammers on the rotating disc COMPACTS and DENSIFIES lower sand and low-water-cement ratio mixes throughout the slab thickness. Where topping is applied to the slab, the material is driven in at the bond line.

DURABILITY INCREASED **SHRINKAGE REDUCED**

*Furnished equipped with either gasoline or electric power head.

For information write:

KELLEY ELECTRIC MACHINE CO.

287 Hinman Avenue **Buffalo 23, N. Y.**

In using concrete as the exterior surface of buildings, he cited a number of problems that must be solved. One of the big problems in general building construction is the lack of good job supervision, inspection and control of the concrete. Until closer control is achieved, concrete construction will be used in the supporting framework, but not as the exterior finish.

Aggregate cooling plant

H. H. Roberts, chief engineer, Consolidated Builders, Inc., Mill City, Ore., explained the plant at Detroit Dam for cooling aggregate and cement used in the mass concrete.

"The principal reason," he said, "for specifying temperature control of mass concrete is to reduce cracking caused by thermal expansion and contraction stresses."

At Detroit Dam the coarse aggregate is immersed in water at 35 F until cooled to 38 F. It is then drained and screened to remove excess moisture. Sand and cement are cooled in continuous hollow-flight screw conveyors in which 35 F water is circulated. Heat transfer is through the conveyor surfaces; there is no direct contact with the cooling water. (Tentatively scheduled for June JOURNAL.)

Precast concrete provides protection against atomic blast

Precast concrete presents an excellent means for protection against atomic blast asserted Arsham Amirikian, head designing engineer, Bureau of Yards and Docks, Department of the Navy, Washington, D. C., at the session on precast concrete Wednesday afternoon.

Precast concrete is suitable for emergency shelters and protective structures and is adaptable to existing structures by providing a protective shell. The readily-assembled framing elements could be prefabricated at regional plants and stockpiled at various points for immediate use in an emergency.

"Fast-changing conditions of a world in turmoil have finally brought grim prospect of another conflict whose new weapons may endanger everyone's life—irrespective of boundaries or location," declared Mr. Amirikan. "The destructive effect of the atomic bomb is not confined to a single objective or structure," and the probabilities of damage to any structure in a community are increased greatly.

As yet no clear-cut policies have been adopted by the various local and public agencies regarding the type and extent of protective measures to be used against atomic blast. The technique of thin-shell precast concrete was offered by Mr. Amirikian as a solution in providing shelters, to be used either as an initial shield against blast and radiation or as emergency shelters after attack.

"Standardized designs of framing and methods and procedures of fabrication will unquestionably simplify the task of construction."

Definition of protection

Mr. Amirikian found a clear definition of protection against a weapon difficult to state. The more practical concept, he said, is that it is a means of providing partial security against specified aspects of a given weapon, that is, the use of precast concrete will not assure complete safety; occupants must accept the possibility of danger as a calculated risk. No structure can escape destruction if it is at or near the center of an atomic explosion.

He then illustrated and explained precast structures designed to assure a reasonable degree of personal safety to occupants against the effects of a bomb assumed to explode at an altitude of 2000 ft, similar to the explosions over Hiroshima and Nagasaki. Different protective structures were proposed for an area of ¾-mile radius around the target, an area of ¾ to 1-mile radius, and an area outside 1-mile.

"For an economical and practical shelter design, it will be necessary to utilize the full resistance of a critical member, or the weakest component of framing, just short of collapse," explained Mr. Amirikian.

Shelters vary in target area

In the area closest to ground zero of the air-burst bomb, an earth-covered precast-type shelter is required to provide protection against nuclear radiation. A curved or

"Some last-minute changes will have to be made here." No rest for convention committee chairman Davis or vice-chairman Glenn, as evidenced at the Wednesday evening dinner while Charles H. Purcell, director of public works, California Highway Commission, waits for further developments.

shaped framing outline was recommended. These include ribbed-shell circular frames (precast concrete version of the well-known Quonset hut), ribbed-shell gable frame, and ribbed-shell dome.

Owing to reduced radioactivity outside the ¾-mile radius, the same type structures can be used without earth cover. The area outside the 1-mile radius is considered as the zone of minimum protection and panel and rib framing can be used.

Many types of existing structures, lacking strength and stability to resist blast pressures in this zone, could be provided with the needed protection by an external shell enclosure. This arrangement is adaptable to single-story brick or frame buildings of narrow width by attaching ribbed-shell panels to the brick walls and wooden roof. When the width of the building exceeds 20 ft, the reinforcing panels need an independent supporting system. This means erecting a complete frame to enclose the existing structure. (Published in ACI JOURNAL, Mar. 1951, p. 497.)

Cost—$50 per person

Providing shelters for a community involves a huge construction task and its success depends on our ability to make optimum use of available materials and labor as well as methods of mass production, concluded Mr. Amirikian.

Mr. Amirikian estimated that a structure to accommodate 8 people would cost about $400, or $50 per person. In larger shelters the price per capita would be less.

S. J. Warberg, Giffels and Vallet, Inc., architects and engineers, Detroit, suggested that standard forms could be made so that home owners could use them to produce their own shelters, thus reducing cost.

Precast developments

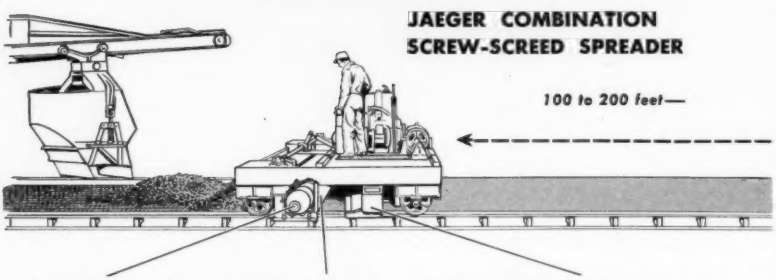
Three papers covered various developments in precast concrete. F. N. Menefee, University of Michigan, Ann Arbor, described advances in precast floor systems.

The high cost of carpentry has brought about a successful attempt to eliminate most of the previously required formwork through the use of precast elements, he stated. The trend is toward units made of high strength, lightweight aggregate under closely controlled factory conditions.

He described briefly the Dox floor and roof system, the F and A system, Joistile and Stresterete. (Tentatively scheduled for September JOURNAL.)

The considerations influencing and determining the design of Stresterete precast structural elements were discussed in detail by A. G. Streblow, president, Basalt Rock Co., Napa, Calif. Precasting has proved itself in a keenly competitive field by increasing speed of construction and consequently reducing costs, he asserted. "Important economies can be effected in jobs requiring substantial quantities of identical units."

JAEGER 3-SCREED PAVING TEAM

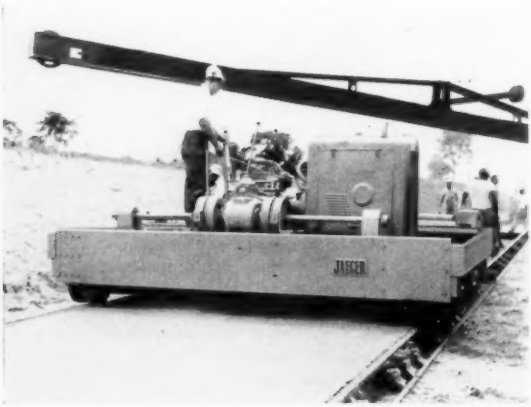


Spreading Screw: Re-mixes, compacts and spreads material evenly, form to form, without shovelers.

Strikeoff Plate: Makes initial strikeoff to approximate grade line (other spreaders do no more than this).

#1 Screed (Metering): Makes precision strikeoff with 12" oscillating shoe. Corrects any excess or deficiency left by strikeoff plate. Saves cost of shovelers for carryback and far costlier backtracking of the paver.

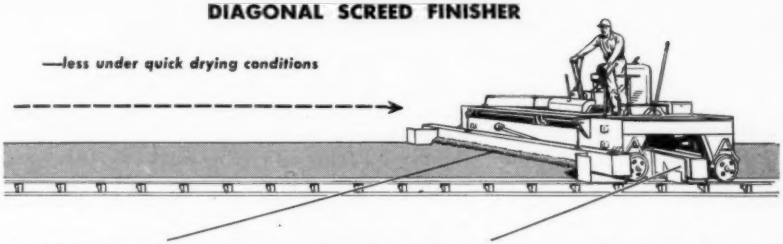
These two machines fully mechanize the laying of highest quality, precision-finished concrete slab. They assure big savings in labor ahead of and behind spreader and finisher—handle full output of largest dual drum pavers—eliminate the costly delays of paver backtracking.



No other spreader does so much or leaves such an ideal condition for the finisher. That's because no other spreader re-mixes concrete on the subgrade as does this Jaeger, nor offers an oscillating metering screed. The result can be seen in this photo taken at rear of the spreader. Widths —10'-15' and 20'-25'.

A two-machine combination that speeds paving, cuts labor costs, and can eliminate a second finisher!

JAEGER TYPE "X" DIAGONAL SCREED FINISHER



#2 Screed (Transverse): Works with just the right roll of material, as "metered" by the spreader. No piles to buck, no high or low spots—uniform compaction assured.

#3 Screed (Diagonal): Pivots to any angle needed to carry material uphill on pitched slab or superelevated curves. Compacts material solidly against higher form. Corrects any irregularities left by transverse screed because it meets material at a different point and at an angle—finishes stiffest mixtures without tearing.

Not only does this Jaeger team speed production and save labor costs. It can also eliminate the need for a second finisher behind the spreader on high production work. (Has already done so in several states.)

Evidence of the Screw-Screed Spreader's metering action—a just right roll of material ahead of the first of the finisher's screeds. It means steady forward progress—no costly delays. It means uniform density and precision finish—a longer lasting, better riding slab. Finisher widths—10'-15' and 20'-25'.

Write for Catalogs CSS-0 and FX-8

THE JAEGER MACHINE CO., 510 Dublin Ave., Columbus 16, Ohio

The use of precast structural elements reinforced with pretensioned steel is still in its infancy, he noted, but its use is bound to expand as practical applications are developed. (Tentatively scheduled for September JOURNAL.)

Precast construction in Canada was then described by Otto Safir, consulting engineer, Vancouver, B. C., Canada. Precast beams and columns were used for the frames of warehouses. In a parking garage, precast elements were combined with cast-in-place members to form an essentially monolithic structure. Another project used precasting to advantage in the construction of a retaining wall.

"The designer need not hesitate to employ complicated shapes if such shapes are those best adapted to the requirements of the structure," emphasized Mr. Safir. "In some cases this leads to economy in concrete and steel."

Precasting opens up many new fields for reinforced concrete, fields which up to now were the prerogative of structural steel, he concluded. (Published in ACI JOURNAL, Feb. 1951, p. 461.)

Economy important

The most important reason for the growth of precasting is its economy, declared F. Thomas Collins, consulting engineer, San Gabriel, Calif., in speaking about new techniques in tilt-up construction.

Tilt-up construction is economical and practical. It will meet building code requirements. However, he urged careful attention be given the erection and joining of these precast elements. (Tentatively scheduled for September JOURNAL.)

The precast concrete session closed with the showing of a film on prestressed concrete by J. R. Janney, Portland Cement Assn., Chicago. The film showed the formwork, placing of prestressing strands, placing and curing of concrete, prestressing and testing of a concrete beam. Mr. Janney reviewed the data collected during the test.

Research

Committee 115 had its annual open session Thursday morning under the direction of Stephen J. Chamberlin, Chairman, and George W. Washa, Secretary. As since 1937, when the first open meeting was held, research men were invited to discuss their problems and things under investigation among themselves without publicity. The convention reporter recorded proceedings only for Committee 115 and ACI headquarters. One had to be present to learn what was discussed.

Ten brief papers from laboratories throughout the country reported:

Tests on the spacing of reinforcement in beams

Prestressing in thin beams

Effect of repeated bond loads on bond-slip curves of bars already carrying axial tension

Performance of automatic freezing and thawing equipment for testing concrete

Pressure method for determining the air content of hardened concrete

Mechanism of frost action in cement paste

Ice prevention by electrically heated concrete pavements

Effect of thermal differences in aggregates on concrete deterioration

Use of radioactive salts in studying properties of concrete

Effect of rate of loading on the compressive strength and modulus of elasticity of concrete.

Contributors to the program were: R. F. Blanks, Bureau of Reclamation, Denver; S. J. Chamberlin, Iowa State College, Ames; Phil M. Ferguson, University of Texas, Austin; Thomas B. Kennedy, Waterways Experiment Station, Dept. of the Army, Jackson, Miss.; Marvin L. Mass, University of Colorado, Boulder; T. C. Powers, Portland Cement Assn., Chicago; C. H. Scholer, Kansas State College, Manhattan; Bailey Tremper, Washington State Highway Dept., Olympia; Stanton Walker, National Sand and Gravel Assn., Washington, D. C.; and David Watstein, National Bureau of Standards, Washington, D.C.

Panel discusses precasting, prestressing, radiant (panel) heat, standard compression test, mass concrete lifts, coatings, stirrups

Of particular interest to builders, superintendents, foremen, engineers and concrete technologists was the panel discussion Thursday afternoon. C. H. Scholer, professor of applied mechanics, Kansas State College, Manhattan, served as chairman and Raymond E. Davis, director, Engineering Materials Laboratory, University of California, Berkeley, vice-chairman.

The panel included engineers well known in the various fields of the concrete construction industry: A. Amirikian, head designing engineer, Bureau of Yards and Docks, Dept. of the Navy, Washington; R. F. Blanks, head, Research and Geology Division, Bureau of Reclamation, Denver; H. J. Gilkey, head, Dept. of Theoretical and Applied Mechanics, Iowa State College, Ames; A. T. Goldbeck, engineering director, National Crushed Stone Assn., Washington.

J. W. Kelly, professor of civil engineering, University of California, Berkeley; H. L. Kennedy, manager, Cement Division, Dewey and Almy Chemical Co., Cambridge, Mass.; T. E. Stanton, materials and research engineer, California Division of Highways, Sacramento; M. A. Swayze, director of research, Lone Star Cement Corp., New York; Bailey Tremper, materials and research engineer, Dept. of Highways, State of Washington, Olympia; L. H. Tuthill, engineer, Bureau of Reclamation, Denver; and I. L. Tyler, manager, Field Research, Portland Cement Assn., Chicago.

Topping gives tough floor

The session opened with a color film on construction of heavy-duty floor topping by Eastman Kodak Co. The procedure for laying bonded concrete floor topping over a concrete slab has been used successfully on several million square feet of floor area at the Eastman plant. A dry mix, rolling and power floating were cited as the essential elements in getting tough, wear-resistant floors.

H. Walter Hughes, Dept. of Public Works, Rochester, N. Y., said a quick check on consistency of the topping is to pack a hard ball of the material; there should be just enough moisture to discolor the hands.

Precast concrete replaces wood forms

What is being done toward the use of thin reinforced concrete slabs in place of wood forms in building construction, the slabs becoming a part of the finished structure?

Few projects have tried to use precast concrete in this way, commented Mr. Amirikian. The Navy built a concrete barge where practically no conventional forms were used; precast slabs and cells were tied together by pneumatically-placed mortar.

An apartment building, only in design stages, plans to utilize 2-in. precast slabs in walls. The walls will be 4 in. thick. Interior forms will be attached to the precast slabs and the interior half of the wall will be cast-in-place, the precast slabs serving both as forms and exterior surface.

Another application is the thin-shelled technique of box construction where vertical forms are 1-in. precast slabs.

"With the present cost of wood forms, the use of thin reinforced concrete slabs offers definite advantages," declared Professor Davis. By using precast slabs as part of the finished structure, it is possible to get the color and texture desired for architectural treatment. In addition, high-strength concrete can be used in the slabs to give impermeable surfaces, which will encourage the use of concrete in building exteriors.

Victor L. Brooks, Texas Concrete Products, Austin, described structural work on a four-story building where precast slabs served as forms. The outer surface was faced with unpolished terrazzo and the back side of the slab had projecting steel dowels to tie into the structural concrete. These slabs were erected as formwork and structural concrete placed between them. He said the project is experimental and some problems remain unsolved.

In using precast concrete as both form and part of the structure, shrinkage of cast-in-place concrete will transfer stresses and cracks to the precast elements.

"The best solution," Mr. Amirikian believed, "is to deal with relatively small

dimensions. If the element is relatively small, the problem will be relatively small in turn." Large elements also complicate casting and handling.

Precast single and multistory buildings

What is the prevailing trend in the use of precast reinforced concrete elements in the construction of single and multistory buildings?

The Navy has been a pioneer in this field, but further work is desirable, emphasized Mr. Amirikian. A housing project of two-story and single-story houses will use "sandwich" panels, built of two concrete slabs separated by an insulating layer. Floor elements are ribbed panels or slabs on joists.

Many houses are being built by conventional precast techniques where floor joists are precast and some walls are precast panels. Cemenstone framing has been used for buildings up to four stories.

He contended that not enough precasting was being used. "Either the contractors are hesitant because they can't see avenues of profit, or are waiting for somebody else to do the pioneering and spade work, or more competition is needed in this field." He emphasized the importance of new methods in conserving materials and cutting labor costs.

"We are now entering a new era, where for economic reasons, precast reinforced concrete construction definitely enters as a competitor of monolithic concrete," asserted Professor Davis.

By using recent developments in precasting, Mr. Amirikian said, materials can be reduced at least 50 percent from the usual monolithic construction. "Two buildings can be built with materials normally required for one." The saving in cost would not be as great, about 25 percent, although factory production methods could cut this further.

"Under factory controlled conditions it is feasible to produce concretes with 8000 psi compressive strengths and within the realm of practicability to build thin sections with 12,000 psi concrete," noted Professor Davis. High elastic limit steel for reinforcing these sections is already available at reasonable prices.

"We should always distinguish between new methods of precasting and conventional methods," Mr. Amirikian said. The conventional method consists of casting essentially the same thing as in monolithic concrete, using about the same amount of material. This was done as early as 1900.

"Why use 2500-lb concrete and ordinary reinforcing, when it is feasible to use 5000-lb concrete with wire mesh reinforcing to get balanced framing?" With special wire reinforcing it is possible to use 8000-lb concrete. As concrete strength is increased, there must be a corresponding increase in grade of reinforcement. This type of precasting promises savings in both materials and cost.

Radiant heat pipes easy to install in slab

What allowance should be made for conduits, sleeves and radiant heat pipes in the design of slabs to overcome the loss of continuity brought about by their inclusion?

Mr. Kennedy replied that a few simple rules usually eliminate any trouble in radiant heat jobs: (1) leave at least ¾ in. protection for all steel; (2) place pipes in top of slab so it doesn't affect tensile steel; and (3) proportion size of pipe according to thickness of slab.

Terrell R. Harper, with George Dahl, architectural and engineering firm, Dallas, Texas, described difficulties encountered in controlling positioning of radiant heating coils near the top of slabs on the ground. To eliminate damage, instead of placing coils on chairs, they placed the lower part of the slab first, positioned coils and then placed rest of slab.

Supervision and inspection are important factors, Mr. Kennedy said, in supporting coils on chairs and keeping them at correct levels in the slab.

Compression test approximate measure of quality

Is the compression test for determining quality of concrete obsolete?

The compression test is not obsolete, asserted Professor Gilkey; it will tell us a lot about many properties of concrete, although it must be supplemented by other tests for those properties that do not vary in direct proportion to compressive strength.

It merely gives an indication, a comparative basis for different batches or mixes. It is a

BOMB SHELTERS

Such structures should be "RIGID". *"The greater the resistance to deformation, the greater the energy required to produce damage"*, says the Atomic Energy Commission.

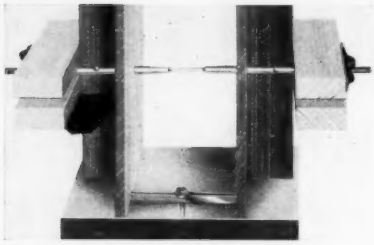
The Dynamic YIELD POINT of Rail Steel is much beyond the *breaking* strength of structural grade bars.

For maximum safety use RAIL STEEL. The new, high, closely spaced lugs and Rail Steel's resistance to elongation prevents concrete from breaking into many dangerous blocks.

PLAY SAFE
BE SAFE
USE RAIL STEEL

More details in the 35 minute, 16 mm., colored, sound film
"RAIL STEEL IN THE WORLD OF TODAY"—revised 1951 technical edition

Write: RAIL STEEL BAR ASSOCIATION
38 S. Dearborn, Chicago 3, Illinois



Williams Clamps showing nail in stud spacing—waler support—and form aligner

Williams—

"Vibra-Lock" Form Clamps

"Super-Hi" Strength Tie Rods, Pigtailed Anchors and Couplings

"Anchor Grip" Form Aligners

"Non-Slip" Waler Supports

For complete information write for our catalog "Form Engineering No. 1955"

WILLIAMS FORM ENGINEERING CORP.

Box 925 Madison Square Station

Grand Rapids 7, Mich.

standardized procedure for measuring a number of properties. The strength shown by a standard cylinder will not be the same as that of some other shape.

"The standard compression test is an approximate measure of quality," said Harlan H. Edwards, with Jones and Bindon, Seattle. It is a rough indication of what can be expected of the concrete in a structure if the conditions of temperature, curing, etc., were comparable to laboratory conditions. It does not show what exists in the structure.

Mr. Edwards advocated that greater use should be made of testing cores from the structure itself to get a true picture of the concrete's characteristics.

"The standard 7-day or 28-day compressive test will indicate the quality of the concrete mixture. It may tell little of an accurate nature about what is in the structure," added Professor Gilkey.

The standard compressive test and compression tests of cores are tied together, he said, in quality control and job control on a project.

Temperature controls mass concrete lifts

What is the effect of high lifts in dam construction?

"There is no effect as far as quality of concrete is concerned. You can place it as high and as fast as you want, provided the forms hold. The only effect in mass concrete is temperature," Mr. Blanks commented. "It is a matter of economy in keeping temperature rise and subsequent fall down by short lifts rather than artificial means." The Bureau of Reclamation usually limits lifts to 5 ft so that nature will aid in cooling the concrete.

R. B. Young, Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada, in describing Canadian practices said they don't worry about heat in higher lifts, nor use cooling coils.

The Commission started using high lifts about 20 years ago when it was found that existing structures were deteriorating at horizontal joints. It was difficult to make joints watertight, so it was decided to eliminate them as much as possible with higher lifts. The structures do not develop serious cracks; core tests and Soniscope tests have shown them to be in good condition.

Coatings protect concrete in water treatment plants

What can be done to prevent deterioration of concrete subjected to chemicals used in water treatment?

The appendix in the 1940 Joint Committee Report was cited as a reference by Professor Kelly. It lists various chemicals that effect concrete and suggests protective coatings.

Low water-cement ratio concrete will reduce deterioration due to some aggressive waters and solutions, Mr. Tyler commented. A high sulfate concentration usually warrants a Type II or V cement. He noted that often the proportions, mix and batching are more important than type and composition of cement.

The most corrosive materials used in water treatment plants are iron and aluminum sulfates and phosphates. Normally these materials are kept away from concrete as much as possible, Mr. Blanks said. If this is not possible, as in feeding tanks, protective treatments that have proved effective are vinyl resins, coal tar and asphaltic paints.

PRESS-UR-METER

FOR TESTING AIR ENTRAINED CONCRETE

NOW IN WORLD-WIDE USE

Universal acceptance, including several foreign countries, has established the PRESS-UR-METER *as the outstanding device for testing air entrained concrete*—faster than any other instrument on the market, precision-made with guaranteed accuracy. Low in cost.

HERE IS BIG NEWS!

SPECIFIC GRAVITY and MOISTURE DETERMINATIONS of aggregates may be quickly made using the NEW CHART now furnished with the PRESS-UR-METER. This Chart has been carefully prepared and numerous tests assure the accuracy and reliability of this method.

LET US TELL YOU about this important extra value of the PRESS-UR-METER for testing air entrained concrete and also designing concrete mixes.

For complete information, write to

CHARLES R. WATTS & CO.

4121 – 6th Ave. N. W. Seattle 7, Wash.

Exclusive sales agents

Construction conditions govern stirrup placement

How should stirrups be placed?

Construction conditions govern it and in most cases it is simpler to make a true U instead of an inverted U, was the opinion of Mr. Amirikian.

J. P. Thompson, Portland Cement Assn., Chicago, commented that some designers say the Code states that hooks should be in the area of compression, which is in the bottom in continuous construction. In preparing ACI's detailing manual, however, a survey found that common practice is to place hooks at the top.

Professor Gilkey stated that as far as bond is concerned, it is no weaker in a region of tension than in a region of compression, so the stirrup can be placed either way.

"How you place stirrups is a question of how they are going to be held in place," said Arthur P. Clark, American Iron and Steel Institute, Washington. "You can't put them in a beam and let them float."

They must be hooked or welded to framing rods. However, it was his impression that straight stirrups, using new deformed bars, would be satisfactory.

"The problem of placing stirrups is a practical one," added R. C. Sandberg, architectural engineer, Rock Island, Ill. Unless the beam is small enough to make the whole reinforcing frame and drop it in place, the stirrups must be placed with hooks at the top to be continuous at the bottom, the other steel resting in the cradle.

Over-stretching prestressed wire eliminates some creep

What allowance should be made for creep or plastic flow in prestress design?

"The allowances for creep, plastic flow and shrinkage are not adequately defined," T. J. Gut, Prestressed Concrete Corp., Kansas City, Mo., answered. Magnel and Freyssinet allow about 15 percent and 10 percent has been used successfully.

Recent tests by Magnel show that by overstretching the wire for a short period some of the creep is eliminated. The Arroyo Seco bridge in California had a design stress of about 120,000 psi, so the wire was prestressed 110 percent, about 132,000 psi, and held for

two minutes which has been determined as a minimum optimum for decreasing wire creep by at least 60 percent. The wire was then released to 106 percent of the design stress and anchored, the extra 6 percent being allowed for shrinkage and plastic flow.

Post-tensioning of members usually waits at least 28 days after casting so a good deal of the concrete shrinkage has taken place, he said.

Freyssinet has suggested that the wire be stretched mechanically a number of times. The more times it is stretched and released, the greater its proportional limit and less the creep. Since wire is usually in large lengths, the method is not economical, Mr. Gut added.

The allowance depends upon the construction technique, Mr. Amirikian said. Where ordinary reinforcing bars are used, the allowance for shrinkage and plastic flow can't be as liberal as for high-yield steel. Four percent is generally accepted as shrinkage allowance and if post-tensioning is used it isn't necessary to figure this. He also allows 4 percent for plastic flow and creep which gives a maximum of 8 percent, subtracting whatever shrinkage there is in the concrete element if it is precast.

Concrete shrinkage was cited as the major problem by several speakers.

Professor Davis questioned whether allowances were great enough in regard to shrinkage and thought the effect of shrinking was greater than that of plastic flow.

He noted that shrinkage, plastic flow and creep of concrete are affected by many things but perhaps the most outstanding is the quantity of water in the mix.

"Other things being equal, the more water in the concrete mix, the greater the drying shrinkage and plastic flow."

Pacific Coast committee

All local arrangements for the 47th annual convention were handled capably by the West Coast committee under the direction of Harmer E. Davis, director, Institute of Transportation and Traffic Engineering, University of California, Berkeley. Robert Glenn, also with the Institute of Transportation and Traffic Engineering, was vice-chairman.

Program development

J. W. Kelly, professor of civil engineering, University of California, was chairman of the local advisory committee on program development. The committee included W. F. Arata, manager, Northern California Chapter of AGC, San Francisco; Hugh Barnes, district engineer, Portland Cement Assn., Los Angeles; Raymond E. Davis, director, Materials Engineering Laboratory, University of California; John J. Gould, consulting engineer, San Francisco; Robert Horonjeff, lecturer and engineer, Institute of Transportation and Traffic Engineering, University of California.

Walter L. Huber, civil engineer, San Francisco; J. E. Jellick, manager, Portland Cement Information Bureau, San Francisco; Walter H. Price, head, Materials Laboratory, Research and Geology Division, Bureau of Reclamation, Denver; Thomas E. Stanton, materials and research engineer, California Division of Highways, Sacramento; G. F. Steigerwalt, president, Haydite Concrete Products Co., San Rafael, Calif.; Bailey Tremper, materials engineer, Washington State Highway Department, Olympia; and Harry A. Williams, professor of civil engineering, Stanford University.

Finance

The finance committee was headed by A. G. Streblow, president, Basalt Rock Co., Napa, Calif., and included J. E. Jellick and Malcolm McIntyre, general sales manager, Basalt Rock Co.

Promotion and attendance

W. A. Marsh, general manager, Permanente Cement Co., Oakland, Calif., was chairman of the promotion and attendance committee. Each committee member was responsible for various areas as follows: Idaho—E. A. Dufford, vice-president, Idaho Portland Cement Co., Inkom; New Mexico—T. Jack Foster, president, Pumice Aggregate Sales Corp., Albuquerque.

Washington—Homer M. Hadley, consulting engineer, Seattle; Oregon—F. E. McCaslin, president, Oregon Portland Cement Co., Portland; Northern California—William

Wallace Mein, Jr., vice-president and assistant to the president, Calaveras Cement Co., San Francisco; Nevada—Robert L. Miller, sales engineer, Ready Mix Concrete Co., Reno; Wyoming—S. W. Russell, vice-president, Monolith Portland Midwest Co., Denver, Colo.; Arizona—H. W. Sayre, sales manager, California Portland Cement Co., Los Angeles, Calif.; Southern California—Byron Weintz, chief engineer, Consolidated Rock Co., Los Angeles; and Colorado, Montana, Utah—Robert W. Winters, general sales manager, Ideal Cement Co., Denver.

Entertainment

Entertainment was under the direction of Mr. Jellick, aided by T. P. Dresser, chief engineer, Abbot A. Hawks, Inc., San Francisco; and E. L. Howard, testing engineer, Pacific Coast Aggregates, San Francisco.

Local arrangements

Chairman of the local arrangement committee was Lee J. Rothgery, associate engineer, Institute of Transportation and Traffic Engineering, University of California. He was aided by Carl E. Monismith, teaching assistant, Division of Civil Engineering, University of California.

Display

The exhibit and display committee was headed by Michael Goodman, professor of architecture, University of California; James Hirst, architect, Berkeley, Calif., was a member of the committee.

Publicity

Publicity chairman was J. I. Ballard, vice-president and editorial director, Western Construction News, San Francisco. Wayne H. Snowden, associate engineer and lecturer, Institute of Transportation and Traffic Engineering, University of California, was also on the committee.

Harmer E. Davis, director, Institute of Transportation and Traffic Engineering, University of California, chairman of the Pacific Coast convention committee. He is presently a member of ACI's Board of Direction and was awarded the Wason Medal with Raymond E. Davis for the 1931 most meritorious paper, "Flow of Concrete under the Action of Sustained Loads."

Committee meetings

Six Institute technical committees took advantage of the San Francisco convention for meetings to consider problems of work extension. Interested visitors were welcomed.

Committee 115—Research (Executive Group)

Nine personnel changes were approved for increased efficiency and coverage. In the direction of further cooperation outside the United States, correspondence will be initiated with Canadian and Cuban research groups and copies of the committee's compilation, "Research Projects in Plain and Reinforced Concrete," are being sent to interested French and Danish research institutions.

In addition to Chairman S. J. Chamberlin, G. W. Washa, secretary, R. E. Davis, D. E. Parsons and M. A. Swayze were present.

Committee 207—Properties of Mass Concrete

Origin of the committee and its work since 1928 were reviewed and the surveys made in 1936 and 1937 were discussed. In the first, representative structures were visited but lack of construction records impeded the work.

In the latter, data are still in field notes but are considered valuable if the structures are revisited.

The recently developed Soniscope was recommended as an important aid in studying mass concrete structures. Several agencies in the United States and Canada are planning to use the device in surveys to be initiated and periodic surveys are being made of 60 to 70 structures of the Hydro-Electric Power Commission of Ontario. On new structures, this agency is compiling complete structural and construction data to aid in the interpretation of later data obtained with the Soniscope.

It was the consensus that study of a few representative mass structures would yield more of value than a more limited study of all dams. It was suggested that compilation of information should not be limited to structures containing more than 150,000 cu yd of concrete but include smaller structures which are of equal interest.

Status of structural behavior measurements in dams, by several agencies in the United States were reviewed briefly. Creep, hydration of cement measured through temperature change, and autogeneous volume change in various structures were mentioned. The use of embedded instruments was suggested as an additional technique to study service behavior.

Members present were R. F. Blanks, chairman, F. Barona, R. E. Davis, J. M. Raphael, secretary, I. L. Tyler, R. B. Young and G. L. Otterson (for W. R. Waugh). Visitors were Douglas McHenry (for TAC), R. F. Adams and C. H. Willetts.

Committee 318—Standard Building Code

Further changes in the Code to eliminate ambiguities were discussed and several design matters considered. Committee work toward a revision of the 1951 Code was outlined and work for the coming year planned.

Committee 323—Prestressed Reinforced Concrete

An informal group discussed the design and application of prestressed concrete. Since its last formal meeting, the committee has worked by correspondence. Progress has been made in the development of notations and definitions and it is expected that some of this material will be made available for publication soon.

Committee members present were A. E. Cummings, chairman, A. Amirikian, Leo H. Corning, Jack R. Janney and D. E. Parsons. Visitors were Phil M. Ferguson, James A. McCarthy, Howard Simpson and Douglas Wood.

Committee 326—Shear and Diagonal Tension

The initial test program on shear and bending in reinforced flat slabs without column capitals prompted some objections. The committee decided that to change the test slabs would throw the study outside the scope of the committee assignment and complicate securing basic data. The title of the project was changed to shearing strength of a reinforced concrete slab under a centrally located concentrated load.

Financial support of the study and the selection of a laboratory to do the work were considered. Additional agencies were proposed to take on part of each of these burdens.

Professor Bresler discussed the theory of the shearing strength of reinforced concrete beams and distributed copies of his paper on this subject. Other committee members were asked to comment on it or to submit similar contributions.

Committee members present were Charles S. Whitney, chairman, Boris Bresler, Arthur P. Clark, Douglas McHenry, D. E. Parsons and C. A. Willson, secretary. A. Amirikian, Miles D. Catton, Leo H. Corning, A. E. Cummings, Joseph DiStasio, Phil M. Ferguson, Jack R. Janney, James A. McCarthy, Howard Simpson and Harry F. Thomson were visitors.

Committee 613—Recommend Practice for the Design of Concrete Mixes

A committee report draft was considered at some length. Decisions were to change the title, proportion mixes on a cement factor basis where durability was not a consideration and to change the arrangement and values in three of the tables in the present report. A new draft report is being prepared for further consideration.

Committee members present were W. H. Price, chairman, Clayton Davis, A. T. Goldbeck, Frank H. Jackson, Henry L. Kennedy, Thomas B. Kennedy, I. L. Tyler and Stanton Walker. Visitors included R. F. Adams, R. A. Burmeister, R. W. Burrows, T. C. Powers and Douglas Wood.

Robert Gros, after-dinner speaker on Wednesday evening, related interesting stories about famous personalities he had met and interviewed.

Not all the discussion took place in formal sessions. Douglas E. Parsons, National Bureau of Standards, makes a definite point. Bob Glenn, vice-chairman of the West Coast committee, hovers in the background while an unidentified member "catches" the ear of A. Allan Bates, Portland Cement Assn.

Three big entertainment features

As hosts, the cement manufacturers, concrete and building industry, and engineers from the 11 Western states planned three entertainment features for the convention registrants. A sightseeing trip through San Francisco's Chinatown was the Tuesday evening feature.

Robert Gros, Pacific Gas and Electric Co., San Francisco, presented entertaining highlights about famous world personalities at the Wednesday evening dinner.

A twilight cruise on San Francisco Bay was Thursday evening.

Retiring ACI President Jackson presents Harry F. Thomson, ACI's newly elected president, the certificate and Wason Medal for the "most meritorious paper" of the year, "Specifications Should Be Realistic."

Courtesy
Chemical and Engineering News

ENTRAINED AIR INDICATOR

Designed for the rapid measurement of entrained air in fresh concrete mixtures by the pressure method as described in ASTM Method C-231. The complete apparatus is comprised of a round bottom, flanged bowl, 8 inches in diameter and 8 inches deep with a capacity of about 0.22 cubic feet; cone-shaped cover with rubber gasket and screw clamps; precision bore glass measuring tube graduated from 0 to 8% air in 0.1% divisions; dial-type pressure gage with zero adjustment; hand pump for applying the pressure; rodding tools; rawhide mallet and strike-off bar for filling the bowl with concrete; funnel and filling-tube for adding water; container of known volume for calibrating and testing the indicator; and brush for cleaning the tube. Each bowl is calibrated and stamped with its cubic capacity. The unit is supplied in a stout wood case with handles and hinged cover for carrying all of the components and accessories. The case also serves as a support for the indicator during the test. Specify No. 25535 Cenco Entrained Air Indicator.

Capacity 0.22 cu. ft.

Dimensions of case: Height, 26 inches; base, 12 by 12 inches.
Approximate total weight, 80 lbs.

CENTRAL SCIENTIFIC COMPANY

Scientific CENCO *Apparatus*

1700 IRVING PARK ROAD, CHICAGO 13

NEW YORK BOSTON SAN FRANCISCO NEWARK LOS ANGELES TORONTO MONTREAL

Annual awards announced

Following a welcome to California from Harmer E. Davis, chairman of the West Coast convention committee, at the general luncheon Wednesday, President Frank H. Jackson presented ACI Awards to W. J. Cheesman, W. S. Colby, J. R. Leslie, Harry F. Thomson and Charles S. Whitney.

Charles S. Whitney, partner in Ammann and Whitney, consulting engineers, Milwaukee and New York, won the Alfred E. Lindau Award . . . . . "in recognition of his many contributions to reinforced concrete design practice." This award was founded in 1947 by the Concrete Reinforcing Steel Institute in honor of the late Alfred E. Lindau, past president of American Concrete Institute. It is given for outstanding contributions to reinforced concrete design practice.

W. S. Colby, structural engineer, Stone and Webster Engineering Corp., Boston, received ACI's Construction Practice Award for his paper "Design and Construction of a Circulating Water Intake," ACI JOURNAL, March 1950. The award was established in 1944 by ACI to recognize the man on the job for his resourcefulness in translating design into the completed structure.

J. R. Leslie and W. J. Cheesman, research engineer and assistant research engineer, respectively, Hydro-Electric Power Commission of Ontario, Toronto, Canada, received the Wason Medal for "noteworthy research" based on their paper "An Ultrasonic Method of Studying Deterioration and Cracking in Concrete Structures," September 1949 ACI JOURNAL.

Harry F. Thomson, manager, Redi-Mix Concrete Division, Material Service Corp., Chicago, was the recipient of the Wason Medal for "the most meritorious paper" of the volume year, "Specifications Should Be Realistic," November 1949 ACI JOURNAL.

President Jackson announced the Board's election to ACI Honorary Membership of Harrison F. Gonnerman, assistant to the vice-president for research and development, Portland Cement Assn., Chicago, and Frank E. Richart, research professor of engineering materials, University of Illinois, Urbana.

New officers elected

Harry F. Thomson, manager, Redi-Mix Concrete Division, Material Service Corp., Chicago, was named president of the Institute at the general luncheon at the 47th annual convention in San Francisco. He succeeds Frank H. Jackson, principal engineer of tests, Bureau of Public Roads, Washington, D. C.

Henry L. Kennedy, manager, Cement Division, Dewey and Almy Chemical Co., Cambridge, Mass., was elected vice-president for a two-year term.

Elected to three-year terms as ACI Directors were Frank Kerekes, assistant dean of engineering, Iowa State College, Ames; G. L. Lindsay, director of tests and research, Universal Atlas Cement Co., New York; I. E. Morris, consulting engineer, Atlanta, Ga.; and Walter H. Price, head, Materials Laboratory, Bureau of Reclamation, Denver.

A. T. Goldbeck, engineering director, National Crushed Stone Assn., Washington, D. C., elected for a two-year term as vice-president in 1950 continues in that office.

In introducing Mr. Thomson as the new president, retiring president Jackson presented him with a section of a new-style deformed bar "as a token of my esteem and evidence of a strong bond between us" in the work of the Institute.

A billion dollar industry

Mr. Jackson then examined Institute activities in relation to the concrete construction industry (see p. 581, this month's JOURNAL).

"The rapid growth and present preeminence of concrete in the construction field is no accident. The combination of concrete and steel in such a way as to eliminate concrete's one structural weakness, low tensile strength, combined with its potentialities for architectural treatment make it an ideal material for building construction."

He commented that ACI has won for itself a high place among the national professional engineering societies of this country. The Institute cannot afford to be complacent about its record, he said. "We should scrutinize continually the methods we employ and ask ourselves whether changes in emphasis or direction of effort may not be desirable."

The national defense program will affect the economic life of the nation and the concrete industry will be faced with a shortage of critical materials, he said.

"The Institute stands ready to cooperate in every way possible in the united effort to create an impregnable defense against any attempt to control our way of life, no matter how powerful it may be or in what form it may appear."

Harry F. Thomson, manager, Redi-Mix Concrete Division, Material Service Corp., Chicago, elected ACI president, has been active in Institute affairs since 1928.

Technical committee members reappointed

Definite terms of membership on ACI technical activities were authorized by the Board of Direction at the San Francisco convention. Chairmen were reappointed for a three-year term and individuals for one and two-year terms. New appointments since the convention will be for terms of two years, expiring in February 1953.

It was emphasized that the policy of definite terms of membership does not mean that a member leave a committee at the expiration of his term, but will provide committee chairmen an opportunity to "weed out" inactive members at the end of each Institute year as a means of stimulating more vigorous committee action.

Who's Who This Month

Frank H. Jackson

Retiring ACI President Frank H. Jackson's address at the general luncheon of the San Francisco convention, "ACI's Place in a Billion Dollar Industry," appears on p. 581.

Mr. Jackson, principal engineer of tests, Bureau of Public Roads, Washington, D. C., has been an ACI member since 1924 and is well-known for his highway and concrete work.

He has been with the Bureau since 1905 and has been successively assistant engineer of tests, engineer of tests, senior engineer of tests and principal engineer of tests.

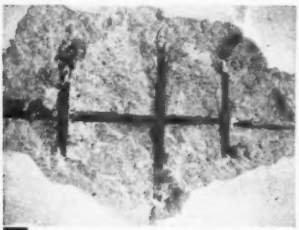
Committee 318

Committee 318, Standard Building Code, under the chairmanship of the late Chester L. Post, proposed revisions of the Code in the December 1950 JOURNAL. Frank Kerekes, assistant dean of engineering, Iowa State College, Ames, who was appointed chairman of the committee, presented the revisions at the 47th annual convention in San Francisco. The revised standard, "Building Code Requirements for Reinforced Concrete (ACI 318-51)," p. 589, was adopted at the convention and ratified by letter ballot.

H. Walter Hughes

H. Walter Hughes, associate engineer, Department of Public Works, Rochester, N. Y., describes how "Thin Concrete Topping Restores Old Pavement," p. 653.

He has been associated with the engineering department of the City of Rochester since 1910 and connected with the materials testing section since 1920. He served as engineer-in-charge of this section for 15 years and has been associate engineer in charge of research for 5 years. He has been connected with investigations on paving work, aggregates, concrete mix designs and exposure studies.



Typical example of spalling. Note corrosion of reinforcing rods exposed by disintegrating concrete.

Reinforced with meshing, the area is restored with gun-applied RESTO-CRETE* by Western Waterproofing Co.

FOR *Lasting* CONCRETE RESTORATION

Specify GUN-APPLIED

RESTO-CRETE*

by WESTERN WATERPROOFING CO.

Sound engineering methods, finest materials, trained technicians and over 35 years' experience assure the job will be done *right* when you specify Western. All work done under contract, fully insured, performance guaranteed. *T. M. Reg.

- Protection from Water Damage (above or below ground, interior or exterior)
- Building Restoration • Tuckpointing

NO MATERIALS FOR SALE • NATIONWIDE SERVICE

for specific data, write:

WESTERN WATERPROOFING CO.

-Engineers and Contractors

1223 Syndicate Trust Bldg. • St. Louis 1, Mo.

Branch Offices and Resident Engineers in Principal Cities

Positions and Projects — ACI Members

McHenry chosen TAC head

Douglas McHenry, head, Structural Research Section, Bureau of Reclamation, Denver, was named chairman of the Technical Activities Committee by the Board of Direction at the 47th annual convention. He succeeds R. B. Young, Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada.

New members include Herbert Insley, National Bureau of Standards, Washington, D. C.; Bryant Mather, Waterways Experiment Station, Corps of Engineers, Jackson, Miss.; and Myron A. Swayze, Lone Star Cement Corp., New York. R. W. Spencer, Southern California Edison Co., Los Angeles, was reappointed to the commitee. L. W. Teller, Bureau of Public Roads, Washington, D. C., and I. L. Tyler, Portland Cement Assn., Chicago, continue as members.

The terms of Frank Kerekes, Iowa State College, Ames, and Nathan M. Newmark, University of Illinois, Urbana, expired this year.

Steam curing committee reactivated

Committee 716, High Pressure Steam Curing, has been reactivated under the chairmanship of W. C. Hansen, manager, Research Laboratories, Universal Atlas Cement Co., Buffington, Ind. The committee was originally activated in 1941 and completed its assignment in 1947. Increased interest and recent developments in high pressure steam curing prompted ACI to reactivate the group at the San Francisco convention.

Appointed to the committee were R. L. Barbehenn, Asbestos-Cement Products Assn., New York; C. C. Carlson, Structural Development Section, Portland Cement Assn., Chicago; H. W. Easterly, Jr., Concrete Pipe and Products Co., Inc., Richmond, Va.; C. R. Eckert, Ruberoid Co., South Bound Brook, N. J.

M. W. Ferguson, Pre-Shrunk Masonry Sales Corp., Roanoke, Va.; S. B. Helms, Lehigh Portland Cement Co., Copley, Pa.; C. R. Hutchcroft, Keasby and Mattison Co., Ambler, Pa.; George L. Kalousek, Owens-Illinois Glass Co., Toledo, Ohio; Harold J. Levine, National Brick Corp., Long Island City, N. Y.; Howard F. Peckworth, American Concrete Pipe Assn., Chicago; J. J. Ryan, Windsor, Ont.; C. L. Schuetz, U. S. Gypsum Co., Chicago; J. J. Shideler, Bureau of Reclamation, Denver; and L. S. Walls, National Bureau of Standards, Washington, D. C.

Reese joins Committee 315

Allen M. Reese, with the R. C. Reese consulting firm, Toledo, Ohio, has been appointed to membership on Committee 315, Detailing Reinforced Concrete Structures.

318 adds new members

Committee 318, Standard Building Code, recently added three new members. They are Leo H. Corning, Portland Cement Assn., Chicago; A. E. Cummings, Raymond Concrete Pile Co., New York; and George E. Large, Department of Civil Engineering, Ohio State University, Columbus.

Legatski named 711 secretary

Leo M. Legatski, assistant professor of civil engineering, University of Michigan, Ann Arbor, has been named secretary of Committee 711, Precast Floor Systems for Houses.

Julian appointed ACI representative

Oliver G. Julian, of Jackson and Moreland, engineers, Boston, replaces the late Chester L. Post as ACI's representative on ASA Sectional Committee A52, Building Code Requirements for Chimneys and Heating Appliances.

Jackson succeeds Gilkey on HRB

Frank H. Jackson, principal engineer of tests, Bureau of Public Roads, Washington, D. C., and past ACI president, has been named ACI representative on the Highway Research Board. Mr. Jackson, formerly alternate representative, suceeeds Herbert J. Gilkey, also a past president of the Institute.

ACI Members meet in Denver

A recent informal meeting of 28 ACI Members in the Denver area featured a discussion of railroad track grouting by George Paris, Structural and Railways Bureau, Portland Cement Assn., Chicago. The group indicated a desire for occasional meetings when speakers with interesting subjects were available. E. W. Thorson, Denver, was one of three elected to a committee to plan future meetings.

Williams resigns as head professor

C. D. Williams has resigned as head professor of civil engineering at the University of Florida, Gainesville, but will remain on the faculty, at least temporarily, for research and development work. He is now serving as special consultant to the firm of Reynolds, Smith and Hills on the $16,000,000 Jacksonville bridge program.

Greulich opens office

G. G. Greulich, until recently consulting engineer in the specialty products division of the U. S. Steel Co., Pittsburgh, has opened an office in Washington, D. C. He will represent the Drilled-In Caisson Corp., W. E. O'Neil Construction Co., Union Metal Manufacturing Co. and Western Foundation Co. He still maintains a consulting office in Pittsburgh.

Mercer visits leading concrete labs

Twenty years ago ACI found it difficult to keep up with comings, goings and changes in residence of L. Boyd Mercer—from Kansas City, Mo., to Bahia Blanca, Argentina, and from Manchester, England, to Melbourne, Australia. In 1933 as author-chairman of Committee 608 he received the Wason Medal for the most meritorious paper, "Sliding Formwork."

Returning to his native Australia, he received the degree of MCE from Melbourne University and joined the Hydro-Electric Commission in Tasmania in charge of design of the 200 ft high concrete arch dam at Butler's Gorge.

For the last seven years he has been chief engineer of Ready Mixed Concrete, Ltd., which operates plants throughout Australia. It was in this capacity that he recently completed a tour of some leading concrete laboratories in the United States, England, France, Belgium, Italy, Argentina and Brazil.

Results of most of Mr. Mercer's recent investigations have been published in Australia, dealing with permeability, volume changes resulting from moisture variations in set concrete and concrete quality control. He presented a paper on aggregate grading at the annual conference of the Institution of Engineers of Australia in Brisbane this month; he will present the principal engineering paper, "Gap Grading of Aggregates," at the Australia and New Zealand Assn. for the Advancement of Science 1951 Congress in May.

Chadwick elected vice-president

Wallace L. Chadwick, for the past five years manager of engineering for the Southern California Edison Co., Los Angeles, has been elected vice-president in charge of engineering and construction. Except for service as engineer and senior engineer with the Metropolitan Water District from 1931 to 1937, Mr. Chadwick has been connected with the Edison Co. since 1922.

William P. Anderson

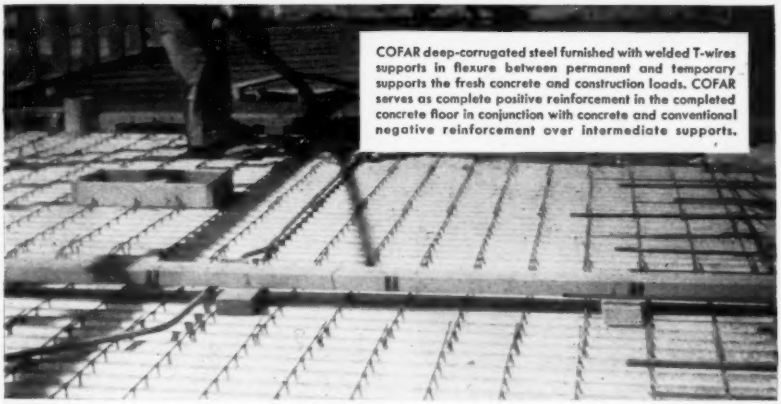
William P. Anderson, Cincinnati, Ohio, past president of the American Concrete Institute (1922-23) and founder of the Ferro Concrete Construction Co., died recently.

A pioneer in reinforced concrete construction, he founded the Ferro Concrete Construction Co. in 1902, served as its president until 1924 and chairman of its board until 1934. He was also active in various civic affairs.

In 1902 he built the 16-story Ingalls building, Cincinnati, probably the first large reinforced concrete office structure erected anywhere. Predictions of its collapse were widespread at the time of erection and many obstacles were placed in the way of its construction. Its 209 ft is, of course, dwarfed by modern skyscrapers.

The Ingalls building is usually considered "the first skyscraper of reinforced concrete in this country."

COFAR COmbination Form And Reinforcement



COFAR deep-corrugated steel furnished with welded T-wires supports in flexure between permanent and temporary supports the fresh concrete and construction loads. COFAR serves as complete positive reinforcement in the completed concrete floor in conjunction with concrete and conventional negative reinforcement over intermediate supports.

STRONG

Guaranteed yield point (.1% offset) over 80,000 psi effective as reinforcement, balanced design, up to full tensile strength over 100,000 psi, independent of form stress.

VERSATILE

Minimum 24ga. —(A_S .35 sq. in. per foot width); maximum 18 ga. —(A_S .73 sq. in. per foot width); to meet full range concrete slab design. COFAR reinforcement satisfies all normal concrete slab design.

Cold-drawn high-strength T-wires not over 6" c.c. are welded to the deep-corrugated steel, and constitute temperature reinforcement in the slab, mechanical anchorage and positive shear transfer from concrete to steel.

PERMANENT

COFAR sheets hot-dip galvanized, with specification heavy galvanizing, provide complete permanence for normal interior exposures. Concrete and steel permanently bonded by chemical union of calcium zincate for all normal loads. Fire resistance for any exposure by lightweight modern ceiling plaster or fibre protection.

ECONOMICAL

COFAR is concrete reinforcement, steel weight substantially equal to conventional reinforcement; *COFAR also is the concrete form.* Form sheeting as well as concrete runways are eliminated. COFAR comes detailed and cut to fit each job. Important material, labor, and time savings are made.

AVAILABLE

Advice for design engineers, review and estimates. COFAR is available — Granco Steel Products Company.

GRANCO STEEL PRODUCTS CO.
(Subsidiary of GRANITE CITY STEEL CO.)
GRANITE CITY, ILLINOIS

SEND FOR AIA FILE NO. 4E4

Straub selected "Engineer of the Month"

Lorenz G. Straub, head, Department of Civil Engineering, University of Minnesota, and director of St. Anthony Falls Hydraulic Laboratory, Minneapolis, was selected as engineer of the month by the *Minnesota Engineer* in its February issue.

An ACI Member since 1926, Dr. Straub, well-known engineering consultant in hydraulics, is vice-president of the executive council of the Union of International Engineering Organizations and was re-elected president of the International Assn. for Hydraulic Research at its recent meeting in Bombay.

In addition he has numerous consulting and advisory assignments for many state, regional, national and international agencies.

Among his special honors in the last few years are the President's certificate of appreciation for wartime services and the award of Officier d'Academie and Order of Palms by the French government.

Marsh appointed vice-president

Wallace A. Marsh, who has been general manager of the Permanente Cement Co., Oakland, Calif., since January, 1949, has been appointed vice-president and general manager of Permanente Cement Co., Glacier Sand and Gravel Co. and Permanente Steamship Corp. He has been associated with various Kaiser companies since 1937. He started as a sand and gravel salesman in the Radum, Calif., plant and subsequently served as manager of operations and sales for Henry J. Kaiser Co.

Steinman receives civic award

David B. Steinman, eminent bridge engineer, was recently presented a medal for his civic contribution in remodeling the Brooklyn Bridge and its approaches by the Greater New York Civic Center Assn. and 55 civic, historic, architectural and scientific organizations. This inaugurates a series of annual awards "for outstanding contributions toward the improvement, preservation and restoration of downtown Old New York City." Other awards went to Commissioner Robert Moses, for completion of the Brooklyn-Battery tunnel; Borough President Robert F. Wagner, Jr., for completion of the Battery Park underpass; and Arthur D. Whiteside, for the new Dun and Bradstreet building.

In 1948, the New York municipal authorities engaged Dr. Steinman to make studies and draw plans for reconstructing the old Brooklyn Bridge to increase the capacity and accommodations of the bridge and approaches from two lanes to six lanes of modern highway traffic.

Beatty named testing engineer

James L. Beatty, formerly senior testing engineer, Pacific Islands Engineers, Guam, is now testing engineer with the California Division of Highways, Sacramento.

Knickerbocker joins Missouri company

C. J. Knickerbocker has been named assistant superintendent of production, Missouri Portland Cement Co., St. Louis. He was previously associated with the Carolina Giant Cement Co., St. George, S. C., in a similar capacity.

Bogue to lecture in Spain

R. H. Bogue, director of the Portland Cement Assn. Fellowship at the National Bureau of Standards, Washington, D. C., recently left on a European tour. He has been invited to give a series of lectures at the Instituto Tecnico de la Construccion y del Cemento in Madrid, Spain.

Mackinac Straits bridge feasible

Three leading bridge designers, David B. Steinman and Othmar H. Ammann, New York, and Glenn B. Woodruff, San Francisco, join in the idea that a Straits of Mackinac bridge in northern Michigan is physically and economically possible—total cost, including financing, about 87 million dollars.

The complete structure would be 5 miles long. A main suspension span of 3800 ft would be second only in length to the Golden Gate Bridge in San Francisco. Side spans from main piers to anchorages would be 1500 ft and the remainder of the crossing a series of truss spans on concrete piers. Twenty-two of them would vary from 560 to 302 ft; four spans near each shore would be from 160 to 200 ft.

Steel towers supporting 25.6-in. diameter cables would reach 565 ft above lake level. Cables would be anchored to huge concrete blocks, the southern one 115 x 180 ft extending 140 ft below lake level.

MIT schedules prestress conference

Preliminary plans for a national conference on prestressed concrete, at the Massachusetts Institute of Technology, Cambridge, Aug. 14-16, have been announced.

The conference will be sponsored by a number of professional societies, including ACI. A. E. Cummings, Raymond Concrete Pile Co., New York, was named ACI's representative on the organizing committee. The conference will consider questions which must be answered before the use of prestressed concrete can be extended in American construction.

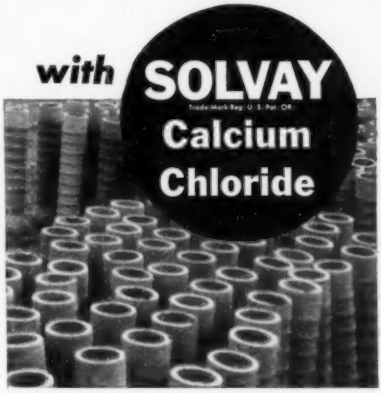
General topics to be considered at the three-day meeting include present and possible future applications of prestressed concrete; manufacture and construction, including materials, techniques and costs; and problems in research and design.

Emphasis throughout the conference will be on design and construction in the United States. Among the questions around which discussion will be oriented are: In what immediate specific applications may prestressed concrete effectively supplement or supplant ordinary reinforced concrete? What will be the most economical mix designs, and what type of prestressing steel is best employed? What construction methods for prestressing are available, and what are the advantages and disadvantages of each? How may the European methods of construction be adapted for efficient and economical use in this country? What (if any) modifications should be made in European methods of design as they are adapted for use here? What about a design code for prestressed concrete?

The conference will be under the direction of Prof. Myle J. Holley, Jr., M. I. T. Department of Civil and Sanitary Engineering, and Prof. Howard Simpson, Department of Building Engineering and Construction. It will be sponsored by the M.I.T. Departments of Architecture, Building Engineering and Construction, and Civil and Sanitary Engineering.

Besides the M.I.T. engineering departments, the conference is being sponsored by national organizations and technical societies —ACI, Associated General Contractors of America, American Institute of Architects, American Society of Civil Engineers and Portland Cement Assn.

DOUBLE YOUR OUTPUT



With the addition of Solvay Calcium Chloride, good concrete products can be made better, faster, at lower cost. Solvay Calcium Chloride helps improve the quality of your products, enables you to strip forms in half the time, gives protection against low temperatures and offers many other advantages.

FREE BOOK AVAILABLE

For complete details, send for free copy of "How to Get Better Concrete Products at Lower Cost." Contains complete information on the use of Solvay Calcium Chloride in cast concrete products. Fill in and mail coupon today.

SOLVAY SALES DIVISION
Allied Chemical & Dye Corporation
40 RECTOR STREET, NEW YORK 6, N.Y.

Please rush my free copy of "How to Get Better Concrete Products at Lower Cost."

Name.....

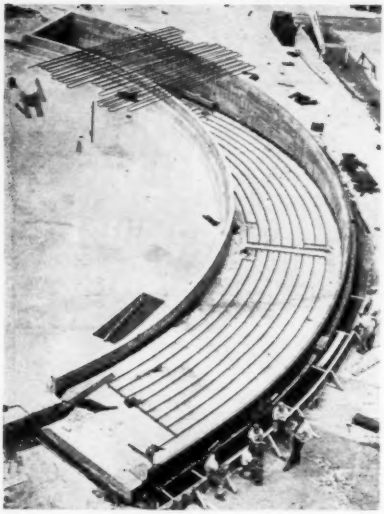
Title.....

Company.....

Address.....

City.....*Zone*.....*State*.....

JC-4



The circular concrete ramp leading down into the garage at the main entrance plaza of the United Nations building in New York City will be kept free of snow and ice by a melting pipe system embedded in the ramp. The parking areas in front of the building will also be kept clear by embedded wrought iron pipe coils warmed when needed by circulating water.

Old volumes wanted

An ACI member would like to buy, at reasonable prices, bound *Proceedings* V. 1 (1905), 9 (1913), 10 (1914), 11 (1915) and 15 (1919). Volumes 1 and 9 would be entitled *Proceedings, National Association of Cement Users.* Volumes 10 and 11 would be entitled *Proceedings, American Concrete Institute* or *Journal American Concrete Institute,* as there was a JOURNAL published for a short period about that time.

Volume 15 might be labeled either *Proceedings, National Association of Cement Users* or *Proceedings, American Concrete Institute.* At the time this bound volume was prepared, the binder evidently was confused because some copies were bound with the name of the old National Association of Cement Users.

Anyone having information about available bound volumes of these years please notify the Secretary who will gladly put him in touch with the prospective buyer.

PROFESSIONAL CARD

L. COFF, Consulting Engineer
198 Broadway, New York 7, N. Y.
PRESTRESSED CONCRETE STRUCTURES
Design, Estimates,
Construction Methods, Supervision

Construction equipment show planned for British fair

Construction equipment will be displayed by 107 exhibitors at the outdoor show in Birmingham, England, during the British Industries Fair, April 30 to May 11. The equipment will be displayed under actual working conditions.

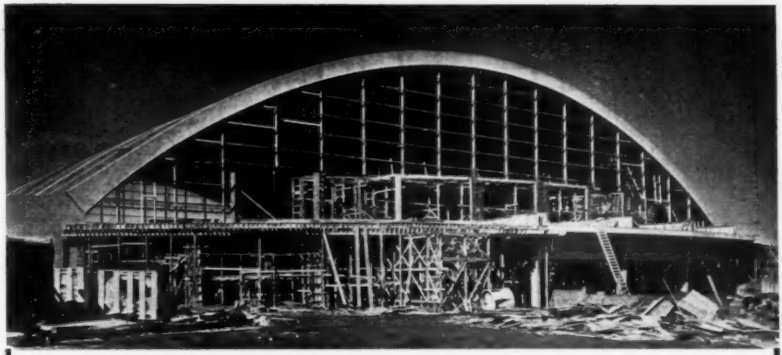
Concreting equipment displayed will range from large weigh-batching plants embodying mixers of 3 cu yd capacity to small portable mixers; also vibratory compacting and finishing machines, surface and internal vibrators, truck mixers, concrete pumps, and bulk cement plant. Mobile plants for crushing, washing and screening aggregates and central batching and mixing concrete plants will also be included in the exhibits.

Fellowship for housing research

Starting in 1951, Massachusetts Institute of Technology will offer each year a Bemis Foundation Fellowship of up to $2500 to a student engaging in a program of graduate research in housing. The research program may be concerned with any significant aspect of housing, from broad studies of needs and requirements to specific problems in management, design, procurement, production and marketing. The fellowships were established by the Albert Farwell Bemis Foundation.

Illinois to hold structural conference

A structural engineering conference will be held at the University of Illinois, Apr. 17-18, sponsored by the Department of Civil Engineering and the Division of University Extension. The program will include general planning of structural projects and recent developments in structural engineering. Topics will include limit design, prestressed concrete, design of superstructure and substructure, and problems of the fabricator and general contractor as influenced by design.



SPORTS ARENA—260-FT SPAN

ROBERTS AND SCHAEFER COMPANY
ENGINEERS — CONSULTANTS
130 N. WELLS STREET, CHICAGO 6
NEW YORK OFFICE—254 W. 54th STREET, NEW YORK 19, N. Y.

SR-4 strain gages—definition

More than 100 types and sizes of SR-4 bonded resistance wire strain gages are now used in engineering and research.

Basically a gage consists of very fine wire grids bonded either to a paper base or into a thin matrix of paper impregnated with Bakelite. In use, it is cemented to parts to be tested in such a way as to be strained either in tension or compression with the test piece. This strain changes the grid's electrical resistance which is measured by a Wheatstone bridge circuit and galvanometer or electronic strain indicator, graphic recorder or oscillograph.

The gages are widely used in stress analysis of parts and structures, including airplanes in flight, airplane propellers, buildings, bridges, tanks, truck bodies, valves, bolts, punch presses and other machines, concrete and ceramic structural members as well as metal; also on rubber, plastics, wood and even on skull bones in studies of shock. They also have been incorporated in special measuring devices such as torquemeters, load weighing tension links and compression cells, fluid pressure cells, and cantilever type load beams, some of which are used in automatic process and machine control equipment.

Concrete has nailability like wood

A concrete into which nails can be driven as into wood, and which resists withdrawal to the same degree that wood does, was reported by *Science News Letter*. It is made of portland cement, vermiculite and vitrified clay granules. Patent 2,542,992 was granted to Lyle Clapper, University City, Mo. It is claimed the new concrete will accept a nail, without bending, driven into it with an ordinary hammer, and without chipping concrete adjacent to the nails.

The vermiculite has the flexibility to yield and receive the nails. It is a mica-like mineral which expands through heat-treatment to a permanent volume about 15 times its original volume and is widely used in lightweight concrete, plaster and as filler insulation.

Honor Roll

New Honor Roll starts

J. E. Jellick, San Francisco, took the lead on the new honor roll that started February 1. Frank Kerekes, Ames, Ia., and Rafael Ruiz, Guatemala, were tied for second place honors.

The Honor Roll that ended last January found the Morgans, Newlin D. of Illinois, and Newlin D., Jr., of Wyoming, holding first and second places.

Where will **you** rank this year?

J. E. Jellick (Calif.)	5
Frank Kerekes (Ia.)	2½
Rafael Ruiz (Guatemala)	2½
Robert G. Deitrich (Md.)	2
H. J. Gilkey (Ia.)	2
Newlin D. Morgan (Ill.)	2

JOURNAL space limitations make it necessary that only those sponsoring 2 or more members be included on the published roll.

New Members

64 New Members

The ACI membership total reached 5242 on March 1. During February, 64 new members joined the Institute. These included 33 Individual Members from the United States and 7 from foreign countries; 2 Corporation Members; 10 Junior Members; and 12 Student Members.

California, ACI's leading membership state, had 14 new members. The new members from outside the United States came from Australia, Belgium, Cuba, Guatemala, Japan, Mexico, Norway, Spain and Venezuela.

Individual

ALEXANDER, JOHN A., HUNTINGTON PARK, CALIF.
BACKSTROM, JAMES E., DENVER, COLO.
BARNHILL, A. V., LOS ANGELES, CALIF.
BEAVERS, MERWIN GORDON, AUSTIN, TEXAS
BENJAMIN, IRWIN A., UNIVERSITY CITY, MO.
BERGER, F. E., CHAMPAIGN, ILL.
BLAIR, PERCY FOX, TULSA, OKLA.
BROOKS, VICTOR LEE, AUSTIN, TEXAS
CECCOTTI, LEE R., SAN FRANCISCO, CALIF.
COHEN, EDWARD, BROOKLYN, N. Y.
DEL CASTILLO, ALBERTO COLONIA CLAVERIA, MEXICO D. F., MEXICO
DE YORK, V., BRUSSELS, BELGIUM
FERRY, WILLIAM F., GLENDALE, CALIF.
FOLSOM, ROLFE A., SAN JOSE, CALIF.
FRUND, P. F., SAUSALITO, CALIF.
GIMESY, OSCAR A., MELBOURNE, AUSTRALIA
GOLDBERG, ALBERT, BOSTON, MASS.
GUIROLA L., ALFONSO, GUATEMALA, GUATEMALA
GURSOY, SUHA, SANTA FE., N. M.
HOOPE, JOHN H., ALEXANDRIA, VA.
ISELIN, DONALD G., SANTA BARBARA, CALIF.
JOHNSON, CARL B., SAN MARINO, CALIF.
KONDO, YASUO, KYOTO, JAPAN
MANTEL, BERNHARD, JERSEY CITY, N. J.
OBIOLS, JULIO E., CIUDAD NUEVE, GUATEMALA, GUATEMALA
RAND, ROLAND B., JR., LYNN, MASS.
REEDER, KENNETH A., ALTADENA, CALIF.
REYNOLDS, BARNETT HARRISON, STARKVILLE, MISS.
RIPLEY, E. P., VAN NUYS, CALIF.
ROACH, DONALD L., BURLINGAME, CALIF.
ROGERS, WILLIAM N., ALHAMBRA, CALIF.
ROWLSON, ROBERT, DETROIT, MICH.
TOPPING, C. H., WILMINGTON, DEL.
VERNER, EDWIN ABERCROMBIE, BERKELEY, CALIF.
WIEST, CLAYTON CLARK, JR., SALT LAKE CITY, UTAH
WIGGINS, A. ROBERT, BALTIMORE, MD.
WIGGINS, BENN A., BALTIMORE, MD.
WILSON, ROBERT O., HICKSVILLE, L. I., N. Y.
WINCHESTER, THOMAS H., JR., MACON, GA.
YOSHIDA, YOSHIO, TOKYO, JAPAN

Corporation

HARTER MARBLECRETE STONE CO., INC., OKLAHOMA CITY, OKLA. (JULIAN C. BROWN)
LABORATORIO CENTRAL DE ENSAYO DE MATERIALES DE CONSTRUCCION, MADRID, SPAIN (F. DEL POZO)

Junior

ALTIZER, FREDERICK J., MARTINSVILLE, VA.
BRILLEMBOURG, DAVID DARIO, CARACAS, VENEZUELA
BRORSON, DONALD L., SAN DIEGO, CALIF.
ESCHENBRENNER, HECTOR EUGENE, COLUMBUS, OHIO
ETHERIDGE, OBIE L., AUSTIN, TEXAS
MORRISETT, RALPH NORMAN, SPRINGFIELD, ILL.
PFEIFFENBERGER, LUCAS E., ALTON, ILL.
STOLE, OLE, DRAMMEN, NORWAY
WALLACE, JOHN THOMAS, JR., DECATUR, ILL.
WRIGHT, COURTNEY M., LAKELAND, FLA.

Student

BOBKOFF, KENNETH BRUCE, AMES, IA.
BRADLEY, JOHN R., AMES, IA.
BYRNE, SYDNER H., AMES, IA.
DE CANCIO, EDILBERTO RODRIGUEZ, HABANA, CUBA
CHAN, SAI-PAK, URBANA, ILL.
KOOSE S., FEDERICO, GUATEMALA CITY, GUATEMALA
LAMB, DONALD R., LARAMIE, WYO.
OLIVARES, J. FRº., NOTRE DAME, IND.
PELLECER E., J. ANTONIO, GUATEMALA, GUATEMALA
RUBIO AGUILAR, RODOLFO, GUADALUPE, MEXICO
SCHULTE, MAURICE M., AMES, IA.
SWALE, ALBERT R., JR., AMES, IA.

Are YOU

"MEMBER CONSCIOUS"

? ? ?

SYNOPSES of recent ACI Papers and Reports

Institute papers of this JOURNAL Volume 22 are currently available at prices indicated. Please order by title and title number.

SOME OBSERVATIONS ON THE USE OF REINFORCING STEEL IN CONCRETE PAVEMENTS.....47-1

Price 35 cents.

BENGT F. FRIBERG—Sept. 1950, pp. 1-16 (V. 47)

The paper contains a few accumulated observations from a review of literature on the evolution of reinforced concrete pavement designs, with reference to various systems of reinforcement which have seen extended use. Typical structural concrete pavement failures are described. Trends in design and reinforcement practice are shown, with special reference to recent developments. Pertinent findings of a few published pavement surveys are cited, with special attention to the 900-mile Louisiana pavement survey made in 1945. The need for performance information and additional research is stressed.

TESTS OF PAPER MOLDS FOR CONCRETE CYLINDERS.....47-2

Price 35 cents.

ROBERT A. BURMEISTER—Sept. 1950, pp. 17-24 (V. 47)

Concrete test cylinders cast in a new type paper mold had a compressive strength lower than that predicted for the concrete mix used. Investigation showed that cracks and mechanical injuries to the outer shell of the concrete cylinder caused by movement of the paper stock during the first 24 hours of curing reduced the strength of the cylinder. To a lesser degree this was true also of the paraffined paper molds in common use for casting test cylinders, specimens cast in both types of paper molds showing lower strengths than test cylinders from the same mix cast in steel molds.

ADMIXTURES IN CONCRETE.....47-3

Price 60 cents.

W. T. MORAN, F. H. JACKSON, BRUCE E. FOSTER and T. C. POWERS—Sept. 1950, pp. 25-52 (V. 47)

Five papers by members of ACI Committee 212, Admixtures, are, because of their common general subject, presented together.

Various admixtures are discussed briefly as an introduction to more detailed treatment of air-entraining materials. The relative merits of admixtures and interground agents are considered. Optimum ranges of air content for different structural uses are given with particular reference to pavements.

The advantages and disadvantages of several types of admixtures used in the fabrication of various concrete products, such as building block, cast stone, pipe, cribbing and curbing, are discussed. The admixtures considered are classified into the following groups: accelerators, air-entraining agents, gas-forming agents, water repellent agents, and workability agents.

The factors affecting bleeding characteristics and workability of fresh concrete are reviewed and the effect of admixtures on these properties is assessed.

Present knowledge of admixtures in counteracting alkali-aggregate reactions is reviewed. It is emphasized that further studies may revise thinking in this field.

The effectiveness of various concrete admixtures in inhibiting the capillary flow of water and the flow of water under pressure is considered. The types of admixtures included in the discussion are accelerators, soaps, butyl stearate, finely subdivided dry materials, mineral oil, workability agents, and a miscellaneous group of proprietary compounds.

IMPROVED SONIC APPARATUS FOR DETERMINING THE DYNAMIC MODULUS OF CONCRETE SPECIMENS.....47-4

Price 35 cents.

C. E. GOODELL—Sept. 1950, pp. 53-60 (V. 47)

After a brief introduction to sonic testing and a description of commercial equipment, the apparatus built for the Michigan State Highway Department is discussed. Reliable results can be obtained by an unskilled worker with this compact equipment which has twice the frequency band spread of the usual oscillator. A wiring diagram of the sonic apparatus is included.

ANALYSIS OF THREE-DIMENSIONAL BEAM-AND-GIRDER FRAMING.47-5

Price 35 cents.

PHIL M. FERGUSON—Sept. 1950, pp. 61-72 (V. 47)

The beam-and-girder floor with some beams carried directly by columns and others supported on girders is cited as a practical problem in frame analysis that must include the torsional stiffness of the girder. Curves showing how moment coefficients vary with this torsional stiffness are developed for a few simple cases in interior panels. These show the weakness of rule-of-thumb methods.

A practical calculation form is set up for use with the moment distribution method in solving three-dimensional problems of this type.

Proposed Revision of SPECIFICATIONS FOR CONCRETE PAVEMENTS AND BASES (617-44).....47-6

Price 35 cents.

REPORT OF COMMITTEE 617—Oct. 1950, pp. 93-116 (V. 47)

New specifications incorporated include those covering air entrainment, removal of forms, premolded joint fillers and joint filling materials and method of placing reinforcement. Definitions have been added under soil foundation preparation and other parts of this section have been revised.

LINEAR TRAVERSE TECHNIQUE FOR MEASUREMENT OF AIR IN HARDENED CONCRETE.....47-7

Price 35 cents.

L. S. BROWN and C. U. PIERSON—Oct. 1950, pp. 117-124 (V. 47)

The method described for the determination of air in hardened concrete permits the examination of 6 x 8-in. and 6 x 10-in. random plane face-ground hardened concrete specimens which more truly represent the aggregate and air voids in the actual concrete than smaller specimens. The construction and use of the instruments are discussed and results of tests are given. Because of the time and equipment necessary to measure air content by means of the integrator, it is not adaptable to field use. However, as a laboratory tool it provides a means for quick and accurate determination of total air.

INFLUENCE OF THE QUALITY OF MORTAR AND CONCRETE UPON CORROSION OF REINFORCEMENT.47-8

Price 35 cents.

RACHEL FRIEDLAND—Oct. 1950, pp. 125-140 (V. 47)

In tests to determine the influence of the quality of mortar and concrete upon corrosion of reinforcement the variables studied were cement content, water-cement ratio, consistency, grading and depth of cover. The specimens, stored in moist air or exposed to weather, were tested up to the age of 2 years.

The results indicate that consistency has a pronounced effect upon the protective value of mortar and concrete, and that there appears to exist an "optimum consistency" at which the quantity of rust is practically unaffected by time. It was also found that the usual cement contents in reinforced concrete have only a limited effect upon corrosion. It is concluded that water-cement ratio does not in itself control the rate of corrosion of reinforcement.

PROPER SAND GRADING IMPROVES MASS CONCRETE.....47-9

Price 35 cents.

THOMAS B. KENNEDY—Oct. 1950, pp. 141-152 (V. 47)

Two series of concrete mixtures were designed using 6-in. traprock coarse aggregate and eight separate gradings of natural sand ranging in fineness modulus from 3.60 to 1.35. Tests were made of the plastic concrete, and specimens were cast for tests of compressive strength, resistance to freezing and thawing, and drying shrinkage. Both series of concrete mixtures had a cement content of 2.5 bags per cu yd; one had a normal air content—4½ ± 1½ percent in the portion of the mixture passing the 1½-in. sieve—and the other had a high air content—10 ± 2 percent in the portion of the mixture passing the 1½-in. sieve. Tests indicate that good durability in freezing and thawing can be obtained within the normal air content range with fineness modulus between 2.50 and 2.90. With increased air content, however, the fineness modulus range can be increased to extend from 1.58 to 3.24. Compressive strength was generally affected adversely by increased air content, but not to a serious degree. Drying shrinkage was less with normal air content mixes than with high air content mixtures. It was least when a fineness modulus of 2.52 was used, little difference being apparent between the high and normal air content mixes with this fineness modulus. The air-entraining admixture requirement increased greatly as the fineness modulus of the sand decreased. The water ratio also tended to increase with decreasing fineness modulus.

WATER-SOLUBILITY OF ALKALIES IN PORTLAND CEMENT.....47-10

Price 35 cents.

J. L. GILLILAND and T. R. BARTLEY—Oct. 1950, pp. 153-160 (V. 47)

In an effort to show correlation of soluble alkalies with alkali-aggregate reaction, the authors hydrated a number of cements for periods up to 90 days and analyzed water extracts of the ground hydrated cement. However, the correlation with expansions of mortar bars prepared with reactive aggregate was not improved by considering water-soluble alkalies rather than total alkalies.

The rate at which the alkalies become water-soluble in hydrating cement indicates that the alkali-bearing phases in cement hydrate quite readily.

NEW PRESTRESSING METHOD UTILIZES VACUUM PROCESS.....47-11

Price 35 cents.

K. P. BILLNER—Oct. 1950, pp. 161-176 (V. 47)

The method outlined here was developed to simplify prestressing of concrete to make it generally adaptable to American ways of construction. It eliminates costly anchorages; uses large diameter wires (⅜-in. diameter now available on the market), instead of the customary ⅛-in. diameter wire, thus greatly reducing the number of wires required; prestresses all the wires in the building element simultaneously and simplifies forming. A simplified method of design calculations for prestressed concrete and the result of tests of a beam so designed are included.

PROPOSED RECOMMENDED PRACTICE FOR THE APPLICATION OF MORTAR BY PNEUMATIC PRESSURE 47-12

Price 35 cents.

REPORT OF COMMITTEE 805—Nov. 1950, pp. 185-196 (V. 47)

This proposed ACI Standard presents briefly the advantages and disadvantages of pneumatically-placed mortar and establishes recommended practices for placing and mixing shotcrete, qualifications and duties of workmen, preparation of surface before shotcreting, reinforcing, sequence of application, and other items involved in good shotcreting.

DETERMINING OPTIMUM CROSS SECTIONS FOR PRESTRESSED CONCRETE GIRDERS.....47-13

Price 35 cents.

FRED J. UZIEL—Nov. 1950, pp. 197-212 (V. 47)

General solutions are presented for selecting economically optimum cross sections for prestressed concrete flexural members. Such a solution for simply-supported girders of rectangular cross section, for any span and load, assuming the wires prestressed after setting of the concrete and full dead weight to act during the prestressing operation, leads to a design procedure which, in the case considered, is extremely simple and rapid to apply. It also permits comparisons and studies related to the critical cross section to be made in a more general and conclusive manner. For cross sections other than rectangular, the number of variables making the solution more indeterminate in nature, a similar direct solution is not obtainable. However, a rapid way of obtaining the minimum areas of concrete and steel required is suggested.

STEAM CURING PROTECTS WINTER CONCRETING.....47-14

Price 35 cents.

C. O. CRANE—Nov. 1950, pp. 213-216 (V. 47)

The use of live steam for protecting newly placed concrete from freezing weather and for providing initial curing has resulted in excellent concrete in the Enders Dam spillway at no greater cost than less desirable dry heating methods. This brief paper describes in detail the methods used.

ANALYSIS OF CONTINUOUS CIRCULAR CURVED BEAMS.....47-15

Price 35 cents.

BECLA VELUTINI—Nov. 1950, pp. 217-228 (V. 47)

Continuous circular curved beams can be analyzed easily by the moment distribution method if both bending and torsional end couples are considered. Formulas and tables are presented for circular curved beams of constant cross section that give the relations between the end moments and end torques and the corresponding rotations of the end sections. A proposed method of procedure is illustrated in which the bending end couples are kept separate from the torsional couples. The mathematical operations are not difficult as the convergence is rapid, but attention must be paid to the sign convention which must be definite and easy to apply.

SHEAR RESISTANCE OF TILE-CONCRETE FLOOR JOISTS.....47-16

Price 35 cents.

J. NEILS THOMPSON and PHIL M. FERGUSON—Nov. 1950, pp. 229-236 (V. 47)

Tests on certain types of tile-concrete joists indicate that the tile webs are more effective in resisting diagonal tension than is indicated by the current ACI Building Code specification. Stagger of tile joints appears to be unnecessary, since they do not seem to be planes of weakness insofar as diagonal tension is concerned. The tile reduces the deflection of the joist.

SOLUTION OF DIFFICULT STRUCTURAL PROBLEMS BY FINITE DIFFERENCES.....47-17

Price 35 cents.

ALFRED PARME—Nov. 1950, pp. 237-256 (V. 47)

Finite differences can be applied to the solution of those structural problems in which the physical relationships are expressed as a differential equation. Essentially, the technique employed consists of replacing the derivatives of the differential equation by its central difference equivalent. The problem is thus reduced to the simple task of solving a system of simultaneous linear algebraic equations. The numerical computation involved in the procedure is considerably reduced by two devices. First, the number of equations necessary to attain sufficient accuracy is reduced by an evaluation of the error introduced in substituting central differences for derivatives. Secondly, the solution of simultaneous equations is speeded by a systematic rapid tabulation of easily determined values. The procedure is applied to the design of a sheet pile wall, elliptical dome and skewed bridge to illustrate the scope and simplicity of the method.

Proposed Revision of BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE (ACI 318-47).....47-18

Price 35 cents.

REPORT OF COMMITTEE 318—Dec. 1950, pp. 269-276 (V. 47)

Proposed changes decrease the allowable bond stress in plain bars (including the old types of deformed bars) and increase the allowable bond stresses for the new types of bars over those previously allowed for the old types. Top bars, those having more than 12 in. of concrete under them, are assigned lower bond stresses than bars in other positions. All plain bars must be hooked, which corresponds to special anchorage under the old provisions. The new bars develop sufficient anchorage by bond alone to correspond to special achorage with the old type bars. Consequently, all bars under the new provisions correspond to those with special anchorage under the old provisions.

CURING CONCRETE PAVEMENTS WITH MEMBRANES.....47-19

Price 35 cents.

C. C. RHODES—Dec. 1950, pp. 277-296 (V. 47)

To provide data to assess the advisability of continuing membrane curing of concrete pavements as an alternate method, laboratory and field tests were made to compare the effect of storage conditions on the physical properties of concrete, warping, temperature control, and strength and abrasion resistance of concrete cured with membranes and with wet burlap. A survey of pavements cured with clear membranes in spring and summer showed that cracking, when it occurred at all, was found predominantly in pavements laid in the morning hours. Comparing white-pigmented membranes with the usual wet-curing conditions in the field it was found to be efficient, practicable and about half as expensiv s wet curing under the same conditions.

BLADE CHANGES IMPROVE TILTING MIXER.....47-20

Price 35 cents.

GLENWAY MAXON—Dec. 1950, pp. 297-300 (V. 47)

Recent experiments, as well as earlier studies, on changing the blading of tilting concrete mixers so as to improve the quality of the mixed concrete are described. The evolution of the blade shapes and the effect of these changes on the path of the materials through the mixer are illustrated.

PROTOTYPE PRESTRESSED BEAM JUSTIFIES WALNUT LANE BRIDGE DESIGN.....47-21

Price 35 cents.

GUSTAVE MAGNEL—Dec. 1950, pp. 301-316 (V. 47)

The tests made on a prestressed concrete beam of 154 ft 8 in. span, identical to the beams of the main span of the Walnut Lane Bridge in Philadelphia, more than justified the adoption of prestressed concrete for the bridge. The test methods and results are described. The test beam exhibited a safety factor against cracking of about 2, which would be far lower for a reinforced concrete beam. The factor of safety against complete failure was about the same as for reinforced concrete while the deflection was less. It is possible to use prestressed concrete for beams where structural steel can not be used due to excessive deflection. The tests proved that the Walnut Lane Bridge will have an exceptional degree of safety with less weight and greater durability than would be possible with reinforced concrete, as well as being considerably cheaper than the conventional solution.

FINISHING AND CURING: A KEY TO DURABLE CONCRETE SURFACES.....47-22

Price 35 cents.

MYRON A. SWAYZE—Dec. 1950, pp. 317-332 (V. 47)

After a comparison of past and present pavement curing and finishing techniques the significance of timing and character of finishing and the timing and mode of curing are discussed. Laboratory tests are cited to show the effect of time of finishing and curing on surface durability to freezing and thawing. It is recommended that all concrete exposed to frost contain entrained air, have a low water-cement ratio and be thoroughly compacted after placing. A finishing and curing procedure is suggested which is adapted to the ambient conditions and to the hydration needs of the cement.

ECONOMY THROUGH BETTER CONTROL OF REINFORCING STEEL.....47-23

Price 35 cents.

F. TESSITOR and P. ROSEWARNE—Dec. 1950, pp. 333-340 (V. 47)

Difficulties and troubles encountered through the use of reinforcement steels not in strict accordance with present-day specifications are discussed. Data are presented to show the possibility of alleviating the situation for engineers, producers and contractors. Simplification of materials requirements, liberalization of code requirements to permit hot bending of bars and permanent identification of grade of steel would, in large measure, permit designers to apply reinforcement to structures in a more effective manner.

Proposed Revision of MANUAL OF STANDARD PRACTICE FOR DETAILING REINFORCED CONCRETE STRUCTURES (ACI 315-48).....47-24

Price 35 cents.

REPORT OF COMMITTEE 315—Jan. 1951, pp. 349-352 (V. 47)

Changes are proposed in bar designations to conform to the numbered designation of the U. S. Department of Commerce and in all drawings to agree with new bond values and anchorage details for new-style deformed bars. Editorial changes in the text of the Standard are outlined.

COARSE-GROUND CEMENT MAKES MORE DURABLE CONCRETE.....47-25

Price 35 cents.

HAROLD W. BREWER and RICHARD W. BURROWS—Jan. 1951, pp. 353-360 (V. 47)

A test procedure for mortar ring specimens is described. Rings containing coarse-ground cement shrunk less and showed greater resistance to freezing and thawing and to outdoor exposure than those containing fine-ground cement. These laboratory tests indicate that coarse-ground cement produces more durable concrete han fine-ground cement.

SIMPLE EQUIPMENT ECONOMICALLY EXPLORES PRESTRESSING..47-26

Price 35 cents.

MARVIN L. MASS and JACK R. JANNEY—Jan. 1951, pp. 361-364 (V. 47)

A tubular grip utilizing type metal to hold the prestressing wires is described. Other equipment includes a framework against which the prestressing force is applied and adjustable formwork for experimental beams. The equipment is so simple that it can be easily and inexpensively built to permit study of prestressed reinforced concrete in the small laboratory.

LABORATORY TESTS OF SPACED AND TIED REINFORCING BARS....47-27

Price 35 cents.

WILLIAM T. WALKER—Jan. 1951, pp. 365-372 (V. 47)

Tests of beam and pull-out specimens containing spaced and tied reinforcing arrangements indicated that little or no advantage would be obtained by spacing deformed

reinforcing bars at splices. Pull-out tests showed that for deformed bars, placed vertically, in which interlocking of lugs could take place there was a slight increase in strength due to tying the bars. Beam tests showed no significant difference between spacing and tying.

Twelve beams containing three different types of deformed bars either spaced or tied and extending the entire length of the specimens were tested. The sixty vertical pull-outs tested also contained three different types of deformed bars. Half of these were made with the bars spaced and half with the bars tied together. The reinforcing arrangement brought only one bar out of the specimens for pulling; the other was allowed to bear on the base plate.

Spacing of the bars in both beams and pull-outs conformed to the joint code minimum spacing requirement of 2½ diameters center to center with a minimum clear distance of 1½ times the maximum size of coarse aggregate.

FINISHING AIR-ENTRAINING CONCRETE PAVEMENTS.....47-28

Price 35 cents.

CHARLES W. ALLEN—Jan. 1951, pp. 373-376 (V. 47)

Based on a survey of state highway department practices, common difficulties in finishing air-entraining concrete pavements are enumerated. Practices in adjusting transverse finishing machines are given and revised finishing practices are discussed. Delayed finishing, as specified in several states, is considered in connection with the riding qualities of the finished surfaces. On the basis of experience in Ohio it is concluded that smooth pavements can be built of air-entraining concrete without delayed finishing.

EFFECTS OF LATERAL LOADS ON ARCHES.....47-29

Price 35 cents.

JAMES P. MICHALOS—Jan. 1951, pp. 377-388 (V. 47)

The effects of lateral loads on arches and the possible magnitude of these effects are considered. An influence table and influence lines are presented for moments and shears in unbraced parabolic arch ribs of constant cross section. These values are for several ratios of rise to span and several ratios of bending to torsional stiffness. The effect of haunching is studied and its possible importance is assessed. Procedures are presented for drawing approximate and exact curves of moments for unbraced arch ribs and for arch ribs braced with struts normal to the ribs. Numerical studies are included.

GETTING MORE FOR OUR CONCRETE DOLLAR.....47-30

Price 35 cents.

I. E. MORRIS—Jan. 1951, pp. 389-396 (V. 47)

A concrete slab with alternating horizontal elements connected by sloping elements is described and its design is worked out. The system is intended primarily for roofs where an exposed ceiling is desired for economy. It may be used to span considerable distances, either as a simple span or as a series of continuous spans. The members are designed to use both concrete and steel to maximum advantage.

FACTORS INFLUENCING CONCRETE STRENGTH.....47-31

Price 35 cents.

WALTER H. PRICE—Feb. 1951, pp. 417-432 (V. 47)

The effect of mix proportions, type and brand of cement, availability of moisture for curing, accelerators and curing temperatures on the rate and potential strength development of concrete are discussed. The influence of rate and frequency of load applications, dimensions of test specimens and lateral restraint on the indicated strength are also discussed, and information is furnished on the variations in strength which might be expected on a typical job. Compressive, tensile, flexural, bond and shearing strengths are compared, and the strengths of control cylinders are compared with the strengths of cores drilled from structures at later ages. Information is also furnished on strength loss from freezing and thawing and alkali-aggregate expansion.

SONISCOPE TESTS CONCRETE STRUCTURES.....47-32

Price 35 cents.

E. A. WHITEHURST—Feb. 1951, pp. 433-444 (V. 47)

The Soniscope, an instrument which measures group velocities through as much as 50 ft of concrete, was used for the field testing of 13 bridges, one navigation lock, 14 dams and five highway pavements in 12 states. Repeated tests permitted study of changes in the condition of the concrete and the development of group velocities indicating the condition of the structure. The value of the results increases with knowledge of the materials, mix design, method of placement and other characteristics of the structure being tested.

EFFECTIVE SEALING OF CONCRETE PAVEMENT JOINTS.....47-33

Price 35 cents.

H. F. CLEMMER—Feb. 1951, pp. 445-448 (V. 47)

The development of cork, metal and rubber joint sealers is traced and work with thermoplastic and cold-pour joint filling compounds is described. The importance of proper technique of preparing and placing the newer materials is emphasized.

ENTRAINED AIR SIMPLIFIES WINTER CURING.....47-34

Price 35 cents.

JOSEPH J. SHIDELER, HAROLD W. BREWER and WILBUR H. CHAMBERLIN—Feb. 1951, pp. 449-460 (V. 47)

The investigation described was undertaken to determine the winter protection required to protect air-entraining concrete from damage by freezing. Cylinders made with Types II and V cement and various percentages of calcium chloride were cured at temperatures ranging from 10 to 70 F and tested for strength at ages ranging from 3 to 180 days. The resistance of these concretes to accelerated freezing and thawing was compared. The results indicate that the amount of winter protection, as presently specified by the Bureau of Reclamation, can be reduced when air-entraining concrete is used.

PRECAST CONCRETE CONSTRUCTION IN CANADA.....47-35

Price 35 cents.

OTTO SAFIR—Feb. 1951, pp. 461-468 (V. 47)

Precast concrete construction techniques as applied to a warehouse, parking garage and retaining wall project are described. Beams and columns for the precast concrete frames of a warehouse were cast flat in multiple forms on the ground slab. Cold weather required special precautions in mixing, placing and curing the concrete. In a parking garage, precast elements were combined with cast-in-place members to form an essentially monolithic structure. A retaining wall 25-ft high is of precast counterforts and 8-in. wall planks. Principal features of the job were the complicated shape of the counterforts and the weight of the completed units.

FACTORS IN PRESTRESSED GIRDER DESIGN.....47-36

Price 35 cents.

M. FORNEROD—Feb. 1951, pp. 469-480 (V. 47)

Following a general description of the Walnut Lane Bridge the stages of loading of the prestressed concrete girders and the sequence of construction operations as they affected the design are discussed. The owner's stress limitations are listed and longitudinal bending in girders, transverse bending in stiffener diaphrams and shear and principal tensile stress in the girder are considered. Safety factors are considered for various loading conditions.

PRECAST CONCRETE OFFERS PROTECTION AGAINST ATOMIC BLAST.....47-37

Price 50 cents.

ARSHAM AMIRIKIAN—Mar. 1951, pp. 497-516 (V. 47)

Precast concrete is an excellent means for providing protection against atomic blast. The technique is suitable for new construction and is adaptable to existing structures by providing them with a protective shell. Readily-assembled framing elements can be prefabricated at regional plants and stored or stockpiled at various points for immediate use in an emergency.

For design purposes, in this paper, shelters are divided into three groups in relation to their proximity to a probable target. Suggested arrangements and main details of assembly of a number of types of precast framing suitable for each group are presented. A general discussion of the protection problem, the needed weapons data and design criteria are also given.

FALSE SET IN PORTLAND CEMENT.....47-38

Price 35 cents.

R. F. BLANKS and J. L. GILLILAND—Mar. 1951, pp. 517-532 (V. 47)

False set of cement causes difficulties in mixing and placing and even though the stiffening is eliminated by job conditions, extra mixing or the addition of corrective admixtures, undesirable effects on the hardened concrete remain. It adversely affects water requirement, strength, bond between aggregate and matrix, brittleness and cracking, resistance to freezing and thawing, and air-entraining characteristics.

Correctives in the manufacture of the cement are proper cooling of mills or the use of stable calcium sulfate.

DIRECT DESIGN OF T-BEAMS.....47-39

Price 35 cents.

HENRY J. COWAN—Mar. 1951, pp. 533-544 (V. 47)

In designing T-beams by usual methods some initial dimensions of the section must be assumed, either the complete dimensions—and the maximum concrete and steel stresses computed to ensure they are less than the allowable stress—or the effective depth only assumed—with tension area computed and the maximum compressive stress in the flange checked to find if compressive reinforcement is required. The author emphasizes that both methods are likely to produce uneconomical sections and take more time.

The direct design procedure proposed enables the dimensions of a T-beam to be calculated for any given set of conditions. Curves are set up for finding the value of j, and the solution of problems by normal methods and "direct design" are compared by solving six examples. An "equivalent flange" method is proposed for the balanced design of T-beams when the area of compression reinforcement is specified, and results show little difference between exact and approximate methods of design.

ALKALI-AGGREGATE EXPANSION CORRECTED WITH PORTLAND-SLAG CEMENT.....47-40

Price 35 cents.

FEDERICO BARONA DE LA O—Mar. 1951, pp. 545-552 (V. 47)

Rather than a pozzolan, granulated basic blast furnace slag described in ASTM Specification C205 should be considered a latent or potential cement with a high siliceous glass content that requires the presence of hydrated lime and gypsum to hydrate properly. To correct alkali-aggregate expansion, a high proportion of slag (about 50 to 60 percent) should be used, which does not reduce strength; rather than lower percentages (20 to 30) which can not be exceeded with pozzolans unless strength is sacrificed. The portland-blast furnace slag cement produced in Mexico, meets ASTM requirements, presents satisfactory strength, low heat of hydration and low alkali content. The corrective action was investigated using Pyrex glass as reactive aggregate, and $NaOH$ to increase the alkali content of the different cements and blends to the same high value (1.23 percent).

Under similar conditions, with the same high alkali content, much smaller expansions were obtained with slag blends than with straight portlands. It is not intended to compare or recommend the use of slag instead of pozzolans, or the use of portland-blast furnace slag cement instead of modified, low-heat, or sulfate resistant portland cement, since in each case, the availability, cost and special conditions will determine what to use. In many cases, slag can be used advantageously to replace 50 to 60 percent of portland clinker.

LEAN MASS CONCRETE USED FOR INTERIOR OF DAMS.....47-41

Price 35 cents.

BYRAM W. STEELE—Mar. 1951, pp. 553-560 (V. 47)

It is not necessary for concrete in the interior and exterior of a dam to have equal durability. By placing 4-bag concrete on exterior faces and lean mass concrete (2½-bag mix) in the interior, it is possible to achieve both durability and economy in gravity dam construction. Lean mass concrete is important in minimizing volume-change cracking; the ensuing economy is an additional feature. The use of interior and exterior mixes in Corps of Engineers dams is described.

ACI'S PLACE IN A BILLION DOLLAR INDUSTRY.....47-42

Price 35 cents.

FRANK H. JACKSON—Apr. 1951, pp. 581-588 (V. 47)

Retiring ACI President Jackson examines Institute activities in relation to the concrete construction industry. ACI has won for itself a high place among the national professional engineering societies, but that eminence cannot be held without continual vigilance and increased effort on the part of all Institute members. Three major phases of activity are examined—annual and regional meetings, publications and committee functions. Recommendations are presented for improving and increasing Institute activities.

BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE (ACI 318-51).....47-43

Price 50 cents (in special covers).

REPORT OF COMMITTEE 318—Apr. 1951, pp. 589-652 (V. 47)

Supersedes 44-1 and 47-18.

This code covers the proper design and construction of buildings of reinforced concrete. It is written in such a form that it may be incorporated verbatim or adopted by reference in a general building code, and earlier editions of it have been widely used in this manner.

Among the subjects covered are: Quality of concrete; allowable stresses; mixing, placing, curing and cold weather protection of concrete; forms; cleaning, bending, placing, splicing and protection of reinforcement; construction joints; general design considerations; flexural computations; shear and diagonal tension; bond and anchorage; flat slabs; columns and walls; and footings. The quality and testing of materials used in the construction are covered by references to the appropriate ASTM standard specifications.

THIN CONCRETE TOPPING RESTORES OLD PAVEMENT.....47-44

Price 35 cents.

H. WALTER HUGHES—Apr. 1951, pp. 653-660 (V. 47)

Lack of information on bonding new concrete to old led to laboratory bonding tests on wet and dry surfaces. Favorable results led to experiments on topping concrete road slabs, which required special techniques in bonding, screeding, compacting and finishing. No sign of surface disintegration has been observed after 6 years on any of the sections. Results indicate that the use of low water-cement ratio, graded mixes and compaction gives ample bond for thin toppings of floors or badly scaled pavements in which the concrete is sound. Concrete pavements containing low durability aggregates can also be given durable wearing surfaces with thin high-grade toppings.

ALPHABETICAL LIST OF ADVERTISERS

(Page numbers refer to News Letter)

Autolene Lubricants Co. 7
Baldwin-Lima-Hamilton Corporation 12, 13
Bethlehem Steel Company 9
Central Scientific Company 34
Chain Belt Company 11
L. Coff 42
Dewey and Almy Chemical Company 17
Granco Steel Products Co. 39
Intrusion-Prepakt, Inc., The Prepakt Concrete Co. 2
Jaeger Machine Co., The 22, 23
Kelley Electric Machine Co. 19
Lone Star Cement Corporation ..... Inside front cover
Rail Steel Bar Association 27
Roberts and Schaefer Company 43
Solvay Sales Division, Allied Chemical & Dye Corporation 41
Charles R. Watts & Co. 29
Western Waterproofing Co. 36
Williams Form Engineering Corp. 28

The Institute assumes no responsibility for the claims of advertisers. The advertiser is made responsible in the belief that his place in the field will be determined by the public's ultimate measure of his exercise of that responsibility.

DISCUSSION

Discussion closed January 1, 1951

Sept. Jl. '50

Some Observations on the Use of Reinforcing Steel in Concrete Pavements—Bengt F. Friberg
Tests of Paper Molds for Concrete Cylinders—Robert A. Burmeister
Admixtures in Concrete—W. T. Moran, F. H. Jackson, Bruce E. Foster and T. C. Powers
Improved Sonic Apparatus for Determining the Dynamic Modulus of Concrete Specimens—C. E. Goodell
Analysis of Three-Dimensional Beam-and-Girder Framing—Phil M. Ferguson

Discussion closed February 1, 1951

Oct. Jl. '50

Proposed Revision of Specifications for Concrete Pavements and Bases—Committee 617
Linear Traverse Technique for Measurement of Air in Hardened Concrete—L. S. Brown and C. U. Pierson
Influence of the Quality of Mortar and Concrete upon Corrosion of Reinforcement—Rachel Friedland
Proper Sand Grading Improves Mass Concrete—Thomas B. Kennedy
Water-Solubility of Alkalies in Portland Cement—J. L. Gilliland and T. R. Bartley
New Prestressing Method Utilizes Vacuum Process—K. P. Billner

Discussion closed March 1, 1951

Nov. Jl. '50

Proposed Recommended Practice for the Application of Mortar by Pneumatic Pressure—Committee 805
Determining Optimum Cross Sections for Prestressed Concrete Girders—Fred Uziel
Steam Curing Protects Winter Concreting—C. O. Crane
Analysis of Continuous Circular Curved Beams—Becla Velutini
Shear Resistance of Tile-Concrete Floor Joists—J. Neils Thompson and Phil M. Ferguson
Solution of Difficult Structural Problems by Finite Differences—Alfred Parme

Title No. 47-45

Unit Buildings Cut Construction Costs*

By L. G. FARRANT† and W. C. HARRY‡

SYNOPSIS

Design of a parking garage, separating the building into many parts, resulted in a highly functional and flexible low cost structure. The authors recognize that the principle of unit buildings can be applied to any type structure.

A flat slab readily adapts itself to this principle and in this design it was again proved that the methods of analysis recommended by ACI can be applied to a slab of unconventional nature to obtain adequate safe design.

INTRODUCTION

Fifty years ago, the great Swiss engineer, Robert Maillart, experimented with flat slab construction. As early as 1900, he designed buildings which were simple and clean using this structural method.

Since then, flat slab construction has retrogressed. Buildings have been designed with cumbersome drop panels and capitals which have detracted from Maillart's simplicity of design.

His ideal of a balance between function, economy and esthetic value was recently sought in a flat plate parking structure in New Orleans (Fig. 1). Its conception, design and construction were influenced by his objective.

*Presented at the ACI 47th annual convention, San Francisco, Calif., Feb. 21, 1951. Title No. 47-45 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 22, No. 9, May 1951, *Proceedings* V. 47. Separate prints are available at 50 cents each. **Discussion** (copies in **triplicate**) should reach the Institute not later than Sept. 1, 1951. Address 18263 W. McNichols Rd., Detroit 19, Mich.

†Member American Concrete Institute, Consulting Engineer, Miami, Fla.

‡Member American Concrete Institute, Structural Designer, L. G. Farrant, Consulting Engineer, Miami, Fla.

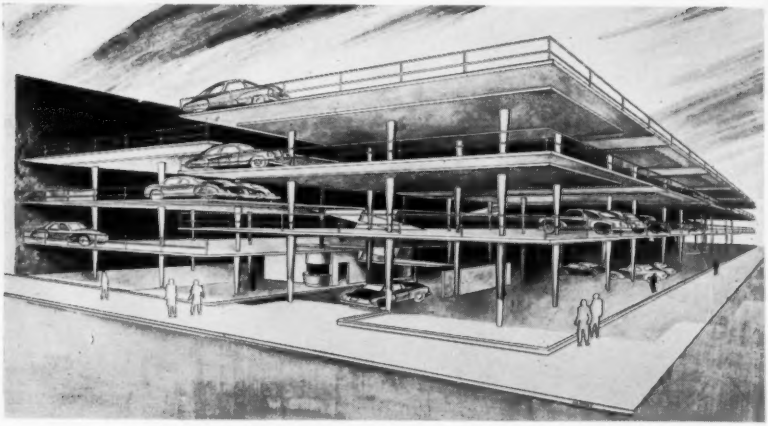


Fig. 1—General view of parking garage

Coordination of the aims was accomplished by sound structural planning and the full utilization of the principle of unit buildings.

UNIT BUILDINGS

Identical parts were arranged so that the completed structure is composed of a repetition of the same units, like a set of toy blocks, or in this case, a set of tables resting on each other (Fig. 2). The blacked-out portion in Fig. 3 indicates one unit building. In this garage, 30 such units were used—all similar in proportion.

Functionally, most buildings consist of working areas with an access of one type or another. In an office structure, the components are offices with either a stair well or an elevator. A multilevel garage, on the other hand, requires a parking area approached by a ramp. The unit building principle applies in either case. The flat slab allows space for parking as well as horizontal movement of cars. Between buildings, a ramp is supported for access to the parking space (Fig. 4). Because the units can be separated, both horizontal and vertical movement is provided without complicating the structure.

Fig. 2—Longitudinal half section of unit building

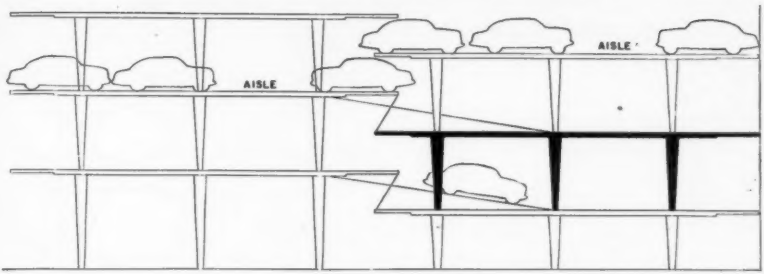


Fig. 3—Cross section showing unit building and relationship of automobiles and ramps

Function dictated certain features of the garage. For example, cantilevers were overlapped at the center of the building for the most efficient use of space (Fig. 5). With this arrangement, one extra row of cars can be accommodated. The cantilevers were further justified because of considerable encroachment of the foundations of the adjoining building.

The overlapping made relatively long cantilevers necessary. Because of the excessive moment thus developed in the columns, large supports would have been required. A tapered column hinged at the base (Fig. 4) eliminated this need by reducing the moment in the columns. The hinge at the base of each maintained the nature of the unit building by avoiding the transmittal of bending moment from one building to another.

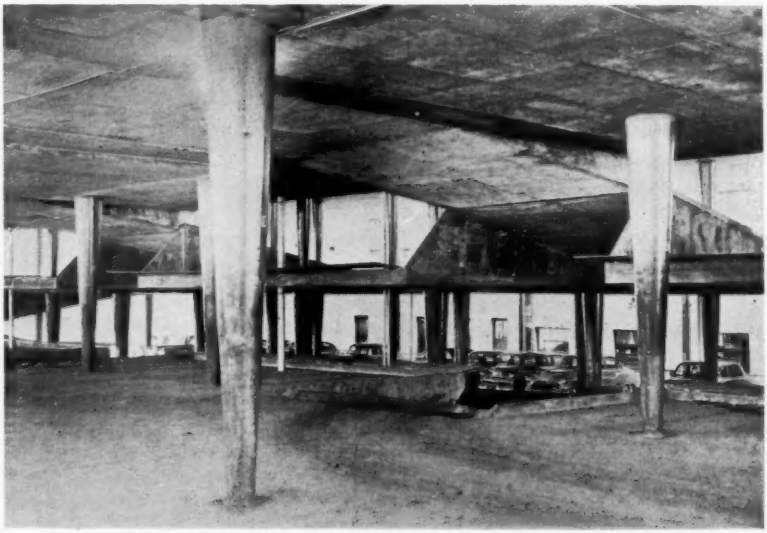


Fig. 4—Unit buildings and adjoining ramp slabs

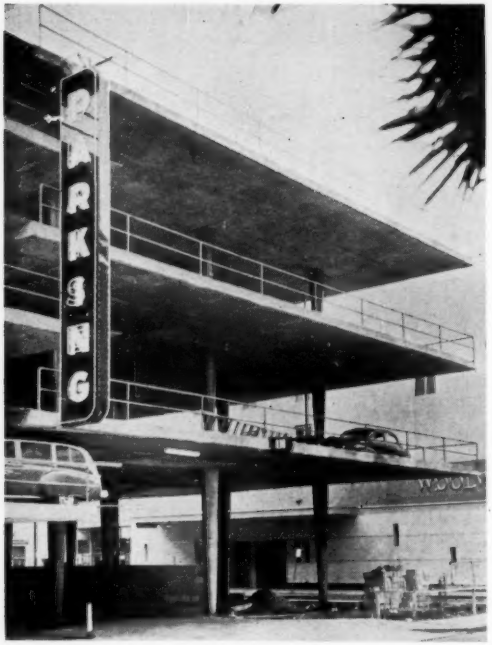


Fig. 5—Overlapping of cantilevers increased space efficiency

The hinge construction was accomplished by transferring column reactions to a 3½-in. diameter cold rolled shaft (Fig. 6), which was set in a socket at the base of a column (Fig. 7). The socket was fabricated of plates and another section of shaft which carried the reaction to the column below. By welding the column bars to the shaft (Fig. 8) and imbedding the shaft in concrete the axial load was transferred from column to shaft and shaft to column. Relying on the relative stiffness of the members to give hinge action the ends of the shaft were not crowned to obtain point bearing.

The column also provided a maximum amount of parking area at the tapered base and eliminated the need for shear heads.

Finally, the jointed parts in unit buildings overcame the ambiguity of control joints and expansion joints required in continuous monolithic construction.

HORIZONTAL SEPARATION

Horizontal separation into unit buildings was justified as follows:

1. Over-all width of structure was reduced by overlapping unit buildings.
2. Space was provided to suspend ramps approximately 48 ft on centers.
3. One model analysis of a unit building would be required for the entire structure.
4. Openings for elevators and ducts in future conversions is facilitated by the separation.
5. Utilities and drainage can be concealed in the construction depth between separations.

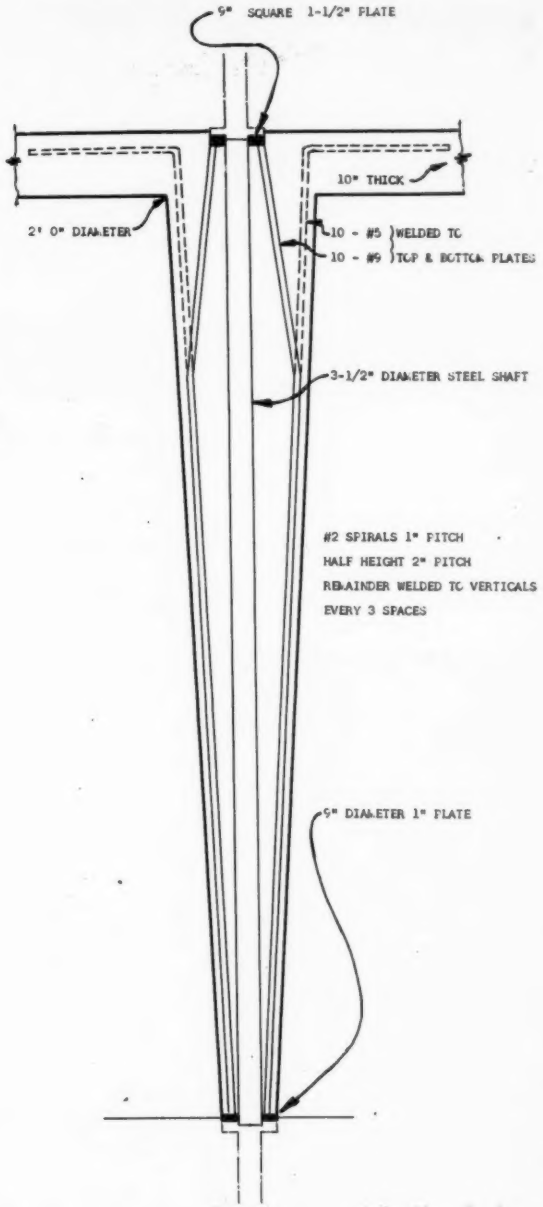

9" SQUARE 1-1/2" PLATE
10" THICK
2' 0" DIAMETER
10 - #5 } WELDED TO
10 - #9 } TOP & BOTTOM PLATES
3-1/2" DIAMETER STEEL SHAFT
#2 SPIRALS 1" PITCH
HALF HEIGHT 2" PITCH
REMAINDER WELDED TO VERTICALS
EVERY 3 SPACES
9" DIAMETER 1" PLATE

Fig. 6—Section through typical tapered column showing plate hinges

Fig. 7—Column sockets and floor slab forms

6. Natural expansion and contraction joints are provided.
7. The unit lends itself to prefabrication; the slabs being lifted by mechanical means to the proper height.
8. Unit buildings could be readily demolished or relocated.

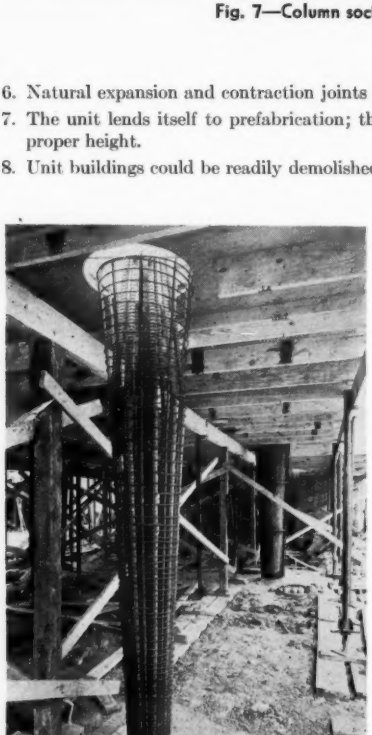


Fig. 8—Column reinforcing in place. Steel column form in background

VERTICAL SEPARATION

Vertical separation in unit buildings is justified by:

1. Effects of differential movement due to foundation settlement, bombing, etc., are minimized.
2. Increasing of story heights for future conversion is possible by jacking unit buildings out of hinge sockets to an elevation considered more desirable.

ECONOMIES

Cost of the New Orleans garage amounted to $400 per car exclusive of property values. This is below the national average for garages. The yardstick provided by American Automobile Association research calls a garage economically sound if the cost is no more than $1350 per car.

This economy results partly from the open decks of the garage, eliminating the need for walls and mechanical ventilation. Because of a number of design principles adopted, the cost is also favorable in comparison with other open-deck garages.

DESIGN

With unit buildings, the conditions of loading can be exactly defined. This means that steel can be cut off at exact points, and the flat slabs can be analyzed—using accepted ACI coefficients even when the slabs are of such an unconventional nature.

Unit buildings were analyzed by dividing them into elastic frames, providing for all variations in the relative stiffness of slabs and columns and the most extreme case of unbalanced design live load. Side sway was taken into account, but the changes in length of members—because of primary stresses, temperature changes, or shrinkage—were not considered. Differential foundation settlement was not an important factor because of the many joints in the building.

The extreme condition of unbalanced loading was applied even though it was not required by the ACI Code—the design live load being less than three-quarters of the dead load.

The moment of inertia of slabs and columns was computed from the gross concrete section. The stiffness and carry-over factors of the slabs were selected from diagrams in PCA *Bulletin* ST 64, and the stiffness of the hinge-tapered columns was computed considering the variable moment of inertia.

In determining slab reinforcement, moments from the bent analysis were reduced to the critical sections and apportioned between middle and column strips in accordance with the coefficients given in the ACI Building Code.

A nomograph was used to expedite the exact location of the numerous slab bars. As an office aid it replaces the common graphic method employing a parabolic curve and an actual plotting of the strip moments. To use the nomograph (Fig. 9), only one setting of the slide rule is required as all values are in terms of the smaller end moment M_1. Once a straight line has been established by the ratios M_2/M_1 and $M¢/M_1$, the moments at critical sections, cutoff points and points of inflection can readily be determined by multiplying the appropriate ratio of M_x/M_1 by M_1.

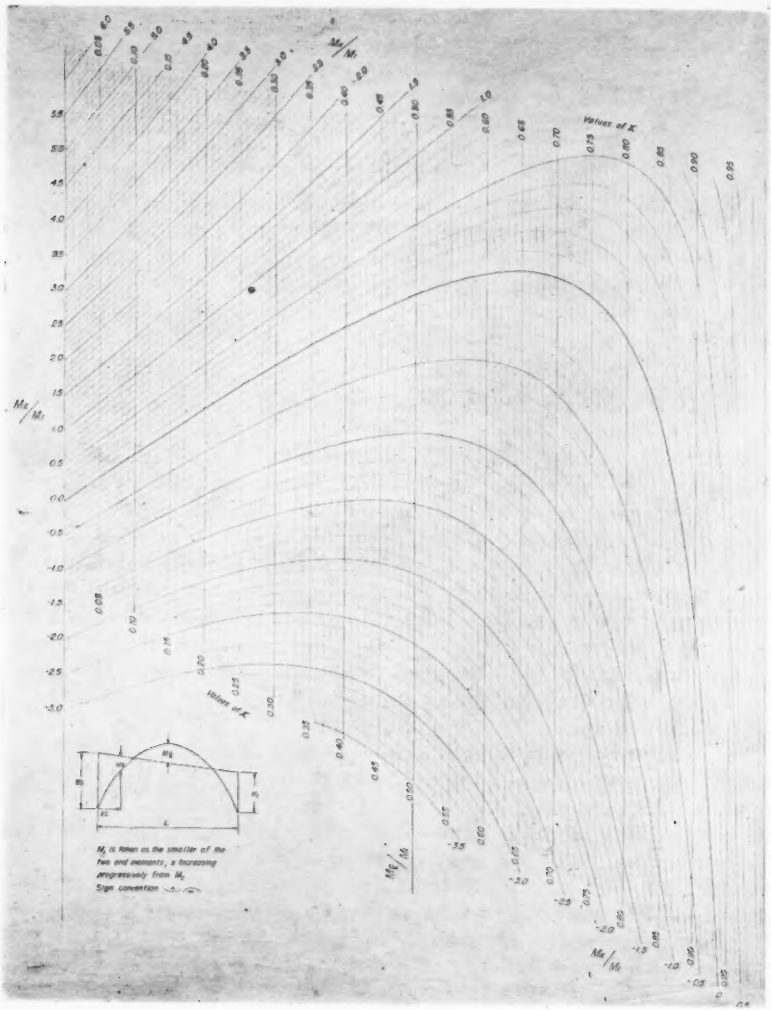

Values of K
Values of K
M_s is taken as the smaller of the two end moments, a increasing progressively from M_s
Sign convention

Fig. 9—Nomograph for locating slab bars

Column strips were considered as extending from the quarter points of the interior span to the slab cutback beyond the column. The remainder of the slabs were considered as middle strips, and the average moments contributing to a middle strip from adjacent bents were taken in the design of that strip. Bending moments on the 6-in. cutbacks were not reduced in recognition of the difference in stiffness of the 10 and 6-in. thick sections.

The moment coefficients were modified as permitted by the ACI Code to more closely approximate the cantilever restraint conditions. A perusal of the relative location of inflection points in a slab of many panels justified this modification.

STRUCTURAL PLANNING

As a result of the structural planning, the thickness of the slab was reduced to an average of 7½ in. as compared with 12½-in. uniform thickness if the garage had been designed as a continuous monolithic structure.

If the columns were spaced at 24 ft instead of alternating 16 and 32 ft as in this garage, a 9-in. uniform slab thickness would be required.

Because of the arrangement used, up to 30 percent of the reinforcing steel was saved even though the average depth decreased (Fig. 10).

Construction economy resulted because concrete did not have to be placed continuously but could be carried on from one unit building to another and one slab to another. As the unit buildings are similar, there is a maximum of standardization and reuse of forms.

High bond steel, conforming to ASTM specification A305, eliminated the use of hooks and reduced anchorage requirements.

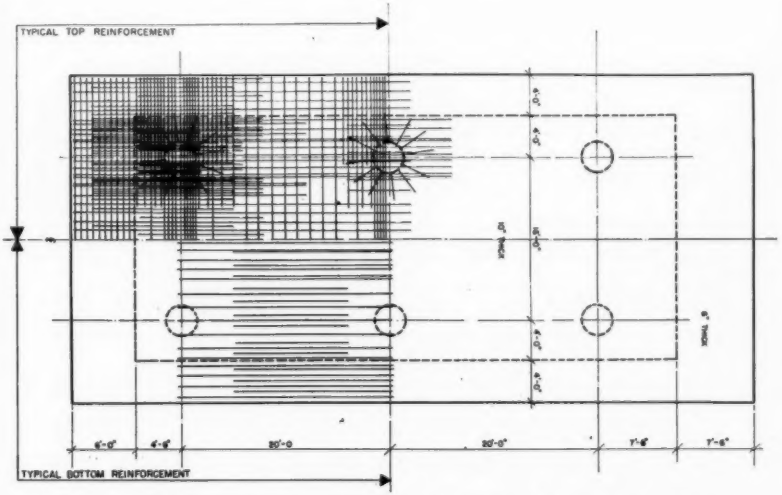


Fig. 10—Reinforcement arrangement and main dimensions of typical unit building

SUMMARY

These data show that the unit building type of construction achieved a balance between function and economy. A structure's esthetic value can be partly ascertained if its attractiveness helps achieve the purpose for which it was built. Since the opening of this garage on Dec. 4, 1950, it has continuously operated at a profit.

The results? An ideal balance between function, economy, and esthetic value.

CONCLUSION

It has been claimed that a relatively low quantity of reinforcement was used, the weight of reinforcement averaging 5 lb per sq ft of slab area.

Recently the authors have been in consultation with the Presan Corporation, Los Angeles, Calif., and as a result are convinced that the weight of reinforcement could have been further reduced by 30 percent to 3.5 lb per sq ft, if the unit building had been investigated by photo reflective stress analysis.

These savings of reinforcement and incidental economies can be applied to all flat plate problems wherever photo reflective stress analysis is used, and the authors recommend that this be considered in problems of this nature.

ACKNOWLEDGMENTS

The firm of Laurence G. Farrant, Consulting Engineer, Miami, Fla., was associated with the firm of Diboll-Kessels, Architects-Engineers, New Orleans, La. The authors acknowledge the cooperation of Gervais F. Favrot and Co., general contractor, New Orleans, Jahncke Service (ready-mix concrete), LaClede Steel Co. (Hy-Bond steel), Pittsburgh Testing Laboratory and all the sub-contractors who participated in the successful completion of this project.

The cooperation of Blaise, Inc., the operators, and Mr. Chaney, regional structural engineer, of the Portland Cement Assn., in the promotion of the functional building is also acknowledged.

REFERENCES

1. Ricker, Edmund R., "The Traffic Design of Parking Garages," The Eno Foundation for Highway Traffic Control, Saugutuck, Conn., 1948.

2. Bowen, G., "Mirrored Model Gives Slab Moments," *Engineering News-Record*, June 7th, 1949.

3. Bill, Max, *Robert Maillart.*

4. Timoshenko, S., *Theory of Plates and Shells*, Engineering Societies Monographs, McGraw-Hill Book Co., New York.

5. "Frame Analysis Applied to Flat Slab Bridges," Portland Cement Assn. *Information Sheet* ST64.

6. Cross, Hardy and Morgan, N. D., *Continuous Frames of Reinforced Concrete*, John Wiley and Sons, Inc., New York.

7. DiStasio, J. and Van Buren, M., "Tall Concrete Buildings Grow in Brooklyn," R/C No. 20, 1947, Portland Cement Assn.

8. Taylor, F. W., Thompson, S. E., and Smulski, E., *Concrete Plain and Reinforced*, John Wiley and Sons, Inc., New York.

9. Kluge, R. W., *Bulletin* No. 322, Engineering Experiment Station, University of Illinois, Urbana.

10. Kleinlogel, A., *Mehrstielige Rahmen*, Wilhelm Ernst and Sohn, Berlin, 1932.

APPENDIX

The concrete mixes, designed by the Pittsburgh Testing Laboratories, are as follows:

Material	*Source*
Cement	Regular portland, Lone Star Brand
Water	City of New Orleans tap
Sand	Jahncke service stock
Gravel	Jahncke service stock
Admixture	Pozzolith—Master Builders, Cleveland, Ohio

ANALYSIS OF MATERIALS

Sand		Gravel				
Sieve size No.	Percent retained	Sieve size	Percent retained		Sand	Gravel
4	9.5	1½-in.	0.0	Fineness modulus	3.00	7.54
8	23.8	1 -in.	8.1	Specific gravity (Saturated surface dry)	2.62	2.55
16	33.9	¾-in.	18.7	Weight, damp loose, lb per cu ft	90.00	90.00
30	48.9	½-in.	51.4	Weight, dry rodded, lb per cu ft	112.50	96.00
50	86.4	⅜-in.	77.3	Moisture, percent	1.5	0.0
100	97.8	No. 4	98.5	Removed by decantation—Finer than 200 mesh	1.0	0.2
				Organic impurities, ASTM	Plate I, Fig. 1+	

MIX DESIGNS

Proportions for one cu yd of concrete

Desired strength, psi	Cement, sacks	Sand, lb. dry	Gravel, lb. dry	Pozzolith, lb.	Entrained air, percent	Total water, gal.
2000	3.67	1273	2022	1.83	3.60	35
3750	5.50	1226	1952	2.75	4.10	34
5000	6.92	1169	1848	3.46	4.30	37

Proportions for one sack of cement

2000	1.0	347	551	0.5	....	9.63
3750	1.0	223	355	0.5	....	6.25
5000	1.0	169	267	0.5	....	5.35

SPECIFICATION REQUIREMENTS

Structural element	Desired strength, psi
Ground slab	2000
Beams and elevated floors	3750
Columns and pile caps	5000

VOLUMETRIC EQUIVALENTS

Concrete strength, psi	Nominal mix	Field mix
2000	1:3.08:5.74	1:3.91:6.14
3750	1:1.98:3.70	1:2.51:3.96
5000	1:1.50:2.78	1:1.90:2.97

ACI Building Code

Is your local code up-to-date?

New ACI Code allows for properties of A305 bars
RESULT—steel savings in reinforced concrete construction

The Code covers the proper design and construction of buildings of reinforced concrete. It is written in such a form that it may be incorporated verbatim or adopted by reference in a general building code.

Changes in the ACI Code decrease the allowable bond stress in plain bars (including old-type deformed bars) and increase allowable bond stresses for new-type bars. According to the new provisions, all plain bars must be hooked, but the new reinforcing bars develop sufficient anchorage by bond to correspond to special anchorage under the old Code. The ACI Code was revised to give designer and builder the benefit of improved bond stresses of new bars, with its ensuing economy.

The Code also covers: mixing, placing, curing and cold weather protection of concrete; forms; cleaning, bending, placing, splicing and protection of reinforcement; construction joints; general design considerations; flexural computations; shear and diagonal tension; bond and anchorage; allowable stresses; flat slabs; columns and walls; and footings.

50¢ per copy—to ACI Members 40¢

AMERICAN CONCRETE INSTITUTE 18263 W. McNichols Rd. Detroit 19, Michigan

Supplementing two previous reports of Committee 312 in 1932 and 1940 this report presents a general method for the design of arches. With a view to the preparation of a final report, extensive discussion is invited to assure a broad coverage of this important subject.

Plain and Reinforced Concrete Arches*

Report of Committee 312

CHARLES S. WHITNEY†
Chairman

BOYD G. ANDERSON† CLYDE T. MORRIS W. S. COTTINGHAM

SYNOPSIS

A general method for the design of arches taking into account all important factors such as dead and live loading and the effects of volume changes, abutment movements and arch deflections. Because of the nonlinear relation between loads and the bending moments caused by deflections, it is found necessary to use an ultimate strength method of design taking into consideration the total effect of critical loading conditions including possible overload. The method permits the proportioning of a rib for optimum stiffness under assumed conditions, thus providing the most economical and satisfactory design.

While it has been general practice to disregard the effect of arch rib deflections, it should be included in the analysis to provide a proper safety factor against buckling and failure due to bending.

INTRODUCTION

Reinforced concrete structures have proved particularly efficient for carrying loads over long spans. Concrete arches, in particular, have been successfully used as structural elements for a wide variety of bridges, hangars, auditoriums and factory roofs.

In some of these arched structures the loads are transmitted to the rib by a shell slab, spanned between the ribs. In others, the loads are carried to the rib by posts or hangers connecting the superstructure to the rib. The first kind of structure is typical of roof construction, the second of bridges. The design principles recommended in this report are applicable to both. It is assumed that the arch ribs are laterally supported to permit a two-dimensional analysis. This support may be provided by a monolithic shell,

*Received by the Institute Dec. 1, 1950. Title No. 47-46 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE V. 22, No. 9, May 1951, *Proceedings* V. 47. Separate prints are available at 50 cents each. **Discussion** (copies in **triplicate**) should reach the Institute not later than Sept. 1, 1951. Address 18263 W. McNichols Rd., Detroit 19, Mich.

This report was approved in form and substance as here submitted by the following members of the committee: Charles S. Whitney, Boyd G. Anderson, W. S. Cottingham and Clyde T. Morris.

†Co-authors.

by bracing between arches or by using an arch cross section of adequate width to be self sufficient.

As an arch rib strains under the action of external loads, internal forces are developed in the rib, which increase until they are in equilibrium with the external loads. These internal forces are the resultants of bending moments and direct thrusts. The relative importance of these two types of resistance depends on the shape of the rib and on the distribution of the external loads. The portion of load causing bending may be decreased by shaping the arch to follow the pressure line of the principal loads.

The design of an arch rib requires the determination of the internal axial forces and bending moments caused by (1) live load, (2) dead load, (3) volumetric changes (shrinkage, temperature, etc.), (4) end displacements, and (5) distortion of the rib due to conditions (1) to (4).

Earlier reports by Committee 312* discussed several of the above factors, including the effect of temperature change, shrinkage and plastic flow in such members. They also proposed a simple, rational and accurate method for predicting the strength of reinforced concrete members under any combination of bending moment and axial load.

This report presents a workable design procedure based upon the proposals of the previous reports. It is purely numerical and includes the evaluation of the rib deflection under load and the maximum total moment in the deflected rib.

LOADING CONDITIONS AND ULTIMATE STRENGTH

The loads acting on the rib must be determined by selecting from experience the critical loads and conditions likely to occur during the useful life of the structure. Due to the uncertainty of some of these conditions, the loads are then multiplied by safety factors larger than one.

Dead load, temperature changes and shrinkage can be predicted with reasonable certainty, while live loads and wind loads are less susceptible to accurate estimate. Larger safety factors are reasonably used in connection with loads subjected to larger variations.

The strength of the rib must be determined on the basis of two limiting criteria: (1) the rib must be capable of carrying without failure the critical load combination occurring during the useful life of the structure; (2) the strains in the rib under working loads should not be so large as to cause excessive cracking or deterioration.

On the basis of these criteria Committee 312 recommends the use of the following two sets of ultimate load equations:

$$U = 1.2\,(B + 2L + W/2) + D \quad \text{(1a)}$$

$$\text{or } U = 1.2\left(B + \frac{L}{2} + 2W\right) + D \quad \text{(1b)}$$

*Whitney, Charles S., "Plain and Reinforced Concrete Arches," ACI JOURNAL, Mar. 1932, *Proc.* V. 28, pp. 479-519.

Report of Committee 312, "Plain and Reinforced Concrete Arches," ACI JOURNAL, Sept. 1940, *Proc.* V. 37, pp. 1-28.

Where U = ultimate thrust-moment strength of the rib
B = thrust-moment strength required by basic load, *i.e.*, by dead load, temperature change and shrinkage
L = thrust-moment strength required by live load
W = thrust-moment strength required by wind load
D = thrust-moment strength required by rib deformation under ultimate load conditions

$$U = K\left(B + L + \frac{W}{2} + D'\right) \quad \text{(2a)}$$

$$\text{or } U = K\left(B + \frac{L}{2} + W + D'\right) \quad \text{(2b)}$$

Where U, B, L, W = thrust-moment strength as in Eq. (1)
D' = thrust-moment strength required by rib deformation under working stress
K = 2 for arches and columns
K = 1.67 for beams

In Eq. (1) and (2) the sum of the strengths is to be understood in a vectorial sense as indicated by the 1940 report of Committee 312.

At all sections both requirements for ultimate strength, as given by Eq. (1) or (2), shall be satisfied.

Eq. (1a) and (1b) provide for overload of the rib. These equations control the section proportions and the reinforcing steel of most arch ribs because of the usual occurrence of large dead load thrusts but small dead load moments. Large thrusts usually decrease the critical effect of moments as described later.

Eq. (2a) and (2b) control the proportioning of those exceptional members in which the axial load is so large that load eccentricities are less than 0.6 the depth. These equations also govern the section proportions and the reinforcing steel of ribs with large dead load moments. If the dead load moment is large, the added moment may overcome the effect of the higher thrusts and the higher coefficients of Eq. 2 are necessary to reduce the stress at working loads.

The ultimate strength Eq. (2a) and (2b) show that the stress at working loads in ribs governed by these equations correspond closely to the stresses allowed by the AASHO-49 Code for similar loading combinations. By Eq. (2a) and (2b) the approximate working stress is 20,000 psi in the reinforcing steel and $0.42f'_c$ in the concrete, including the stress caused by the deflections under these loads.

The following points should be kept in mind with reference to Eq. (1) and (2):

(*a*) Do not overestimate the dead load, since a substantial increase in this load is not possible. Furthermore, the dead load is responsible for most of the thrust and a higher thrust may actually produce less severe conditions than a smaller thrust, as illustrated by the following example.

Assume a reinforced concrete section with a width b = 2.00 ft and a depth t = 3.75 ft, with symmetrical top and bottom steel ($A_s + A_s'$) of 18.72 sq in., subjected to thrusts of (a) 92.5 kips; (b) 736 kips; and (c) 1196 kips. Table 1 shows the ultimate moments according to the ultimate strength design formulas given in the 1940 report of Committee 312.

It is seen from Table 1 that as the thrust increases from 92.5 kips to 1196 kips (an increase of 12 times) the moment or eccentricity strength of the rib *increases* 1.85 times.

TABLE 1—ULTIMATE MOMENTS UNDER VARIED THRUST

Thrust due to external loads, N kips	92.5	736	1196
$K = N/btf'_c$	0.0228	0.188	0.296
Eccentricity at ultimate moment, e_{ult}, ft	16.28	3.252	2.32
Eccentricity ratio, e/t	4.35	0.865	0.620
Ultimate resisting moment for the given N, M_{ult}, ft-kips	1505	2490	2780
Comparison of ultimate resisting moments	0.605	1.000	1.110

The moment strength of a reinforced concrete member continues to increase with increasing axial loads up to eccentricities varying between 0.3 and 0.6 of the depth, depending on the yield point and percentage of reinforcing steel. The moment strength of the rib described by Table 1 will increase up to a thrust of approximately 1800 kips. The moment strength of the rib decreases from this point on, whence the section will be governed by the value of the thrust. The ratio e/t of most arch ribs is so large that an increase in thrust usually entails an increase in moment strength.

In the above example, the rib strength varies by less than 100 percent under a thrust variation of 1200 percent under a given moment. The rib strength may therefore be considered essentially strength to resist moment. However, secondary moments due to deflection of the rib increase with an increase in thrust.

(*b*) Because of the typical behavior of reinforced concrete members under combined direct stress and flexure, and because it is possible to estimate with reasonable accuracy the dead load, temperature and shrinkage effects, the ultimate strengths required by these are lumped under a single term B in both Eq. (1) and (2). It must be noticed that since in Eq. (2) all the moments and thrusts have the same safety factor, the grouping of loads does not affect the value of the ultimate strength U. The grouping does, however, affect the value of U given by Eq. (1).

(*c*) Because of inaccuracies in construction, the dead load may vary both in magnitude and distribution. When the arch axis is designed to conform with the theoretical dead-load pressure line, theoretical moments due to dead load will be low and such inaccuracies may produce appreciable increases in total moment. For example, an anti-symmetrical dead load variation of 5 percent may produce an increase of 20 to 25 percent in the total moment. To provide for such possible dead load variations, the rib should be capable of resisting a partial load equal to 5 percent of the dead load weight in addition to all other loads. This load should be treated as a moving load placed so as to produce the maximum effect at each section.

(*d*) The 1932 and 1940 reports of Committee 312 provide considerable information on the probable values of temperature change, shrinkage and plastic flow.

While temperature, shrinkage and abutment movement stresses are relieved by plastic flow and cracking in the rib, deformation stresses are increased. Records show that cracking and plastic flow have caused failures in major structures many months after decentering. To prevent failures of this type, the rib should be proportioned to control the initial volumetric and displacement stresses, and sufficient steel should be provided to prevent excessive flow under long time loads.

(*e*) Live load, usually specified by the governing code, should be placed for maximum moment at each section.

(*f*) Wind loads, important in long-span arch roof structures, are difficult to evaluate because of the influence of the shape of the structure, screening and dynamic effects. Pressure measurements on existing similar structures are useful in determining these loads, but when these are not available model tests may provide some clues, although the conditions of testing (constant velocity wind on small models) can give results misleading both in magnitude and distribution.

The unrealistic assumption of wind loads providing uniform pressures over the entire roof area ought to be discarded in most cases, since these loads produce small moments, and the thrust increases have a relatively small influence in arched structures.

It is recommended that the determination of wind loads be based upon size, shape, exposure and other characteristics of the structure which influence wind pressure distribution. The

intensity should be obtained from the maximum recorded wind velocity for the area corrected for instantaneous gust pressures.

(*g*) Roof arches designed to follow the dead-load pressure line and subjected to live loads including wind of less than 20 psf have small theoretical deflections. For these structures, safety against buckling may be secured by considering the moments due to displacements obtained by calculating the effect of a minimum live load of 20 psf placed for maximum moment at each section.

(*h*) The coefficients of Eq. (1) and (2) must cover the worst loading conditions anticipated for the structure. They must also provide for inaccuracy in predicting the behavior of the materials, for errors and deficiencies in construction, and for inaccuracies in analysis. By use of the plastic theory of design to predict the strength of the rib and by establishing concrete controls such that the minimum cylinder strength exceeds the design strength, the behavior of the material may be predicted within reasonable limits. Careful construction under rigid specifications may be expected to limit construction errors within tolerances anticipated by the dead load variations considered under (*c*).

The following procedure is recommended to limit errors in the analysis.

ANALYSIS

Basic principle

When a rib is subject to the action of specific external loads, volumetric changes and end displacements, it will deflect elastically a calculated amount. The resulting deflection, however, will create increased moments causing further deviation between the neutral axis of the member and the pressure line, creating still greater total moments. If the rib is too flexible the total moments will gain at a greater rate than the internal forces resisting deflection and the rib will fail.

Although the theoretical stability of arches may be calculated analytically for simple arch forms and cross sections, this determination is of little value unless it includes secondary effects. In fact, if secondary moments are not added to initial moments, the analytical calculation may indicate theoretical stability for a given loading when the rib may actually be unstable, since the total moments may produce local failure.

In evaluating deflection moments, it must be realized that these moments are proportional to the total thrust acting at the time deflection occurs and deflection moments due to separate loads *cannot* be added together to obtain the total deflection moment. Hence, to obtain a given factor of safety in the rib, deflection moments must be calculated using full combinations of loads. Since the deflection effects are nonlinear and increase more rapidly than the loading, the factor of safety providing for overload must be applied to the load *before* the deflection effect is calculated. Otherwise, failure will be caused at a much smaller overload than desired.

Design method

The first step in the design method consists in determining the moments and thrusts in the rib for each of the specified loading conditions, assuming the rib to behave as an elastic member and neglecting the influence of deflections on moments.

In the second step moments and thrusts are combined according to Eq. (1) and (2) and deflection moments are evaluated and added to the total moments obtained in the first step.

The first part of the analysis may be performed by any of the standard methods of analysis described in textbooks on structural analysis. The approximate solution ignoring the influence of moment on rib-shortening, of thrust on angular change, and of curvature on moment of inertia, may be used in most cases without serious reduction in accuracy. When the arch is fixed at the ends and is shaped to follow the dead-load pressure line, coordinates and proportions of the rib, as well as moments and thrusts at the crown, quarter points and springing line may be found directly from tables and diagrams* saving numerous trials and recalculations.

While direct integration of the differential equation of the rib may be used for the second part of the analysis (determination of the deflection moments and check of the buckling stability) when the shape and proportions of the rib lead to a simple equation, the analysis becomes generally impractical for ribs with variable cross section and complex shape. For these cases, a numerical procedure is suggested, which gives deflection, angular change along the rib and deflection moments. The method also checks the stability of the rib, whatever its shape or moment of inertia, and is also useful in determining the most advantageous rib proportions and steel percentages. It can also be used to predict the effect of inelastic strains.

The suggested procedure consists of a series of successive approximations indicating by the rapidity of the mathematical convergence the deflected position of the rib. It may be refined to any degree of accuracy, but time-consuming refinements are not justified whenever the uncertainties in the loads and the physical characteristics involve errors greater than those caused by the numerical procedure.

The numerical procedure consists of the following steps:

(1) The moments and thrusts for each individual loading condition, as determined in the first part of the analysis by neglecting the deflection effects, are combined according to Eq. (1) and (2) to obtain the total moments M_1 and the total thrusts N_1.

(2) The deformation of the rib axis is computed for each combination of loading conditions. For this purpose the rib is divided into a number of panels, the combined moments M_1 and thrusts N_1 are tabulated at each panel point and the angular rotation ϕ and the deflection y at the center of each panel section are computed by means of the following equations:

$$EI\ dy/dx = EI\ \phi = \int M_1 ds = \iiint w\ ds\ dx\ ds \quad \ldots\ldots (3)$$

$$EI\ y = \int EI\ \phi\ dx = \iiiint w\ ds\ dx\ ds\ dx \quad \ldots\ldots (4)$$

These equations express the conjugate shear and the conjugate moment at each panel point.

(3) The above rib deformations give the change in the distance between the rib axis and the pressure line. Assuming all redundant restraints removed, this displacement adds a new moment M_0 equal to the horizontal thrust times the change in position of the rib axis, *i.e.*, a moment equal to the horizontal thrust times the deflection determined in step 2. The moments M_0 cause a change in the redundant reactions, which in turn cause a shift of the pressure line and a correction to the moments M_0, yielding a first correction to the moments M_1 and thrusts N_1.

To find the changes in the initial values of the redundant moment M', the redundant horizontal thrust H' and the redundant vertical reaction $V\ V'$ of step 1, the moment M_0 is applied

*Whitney, C. S., "Design of Symmetrical Concrete Arches," *Trans.* ASCE, V. 88, 1925.

to the rib with the redundant reactions removed. The changes $\Delta M'$, $\Delta H'$, and $\Delta V'$ caused by M_0 are then found by the same equations used in the initial analysis for the determination of the redundants M', H' and V'.

(4) The corrections to moments and thrusts along the rib, ΔM_1, ΔN_1, are then computed and added to the original moments and thrusts, yielding $M_2 = M_1 + \Delta M_1$ and $N_2 = N_1 + \Delta N_1$. Steps 2 and 3 are repeated using M_2 and N_2 for M and N and obtaining further corrections and new values M_3 and N_3. The process is repeated until the corrections become negligible, obtaining the final value of the total rib moment and thrust.

Table 2 illustrates the numerical evaluation of the total moment at the crown of a rib using the loading combination producing maximum positive moment at this point.

The results of Table 2 are shown in Fig. 1, where the graphs of the total moments obtained in the successive cycles are indicated by M_1, M_2, M_3 and M_4.

In Table 2 the summations are extended to half the length of rib because of symmetry. To obtain maximum deflection moments at other points along the arch or under unsymmetrical loading or for unsymmetrical arches, the summations must be extended to the entire length of the arch.

The numerical work of this procedure is selfchecking, since the angular change (conjugate shear) at the end support is known, being zero for a fixed end or a specified value if the abutments move.

SUMMARY

The following points should be noted in connection with the proposed design procedure:

(a) Computations similar to those of Table 2 for both positive and negative deflection moments must be made at sufficient points along the arch to allow the drawing of an envelope curve defining the maximum anticipated deflection moments at any point along the arch.

(b) All computations in Table 2 make use of the original arch summations of elastic weights in the determination of ΔV and ΔH at any cycle, although greater accuracy could be obtained by using the new coordinates of the panel

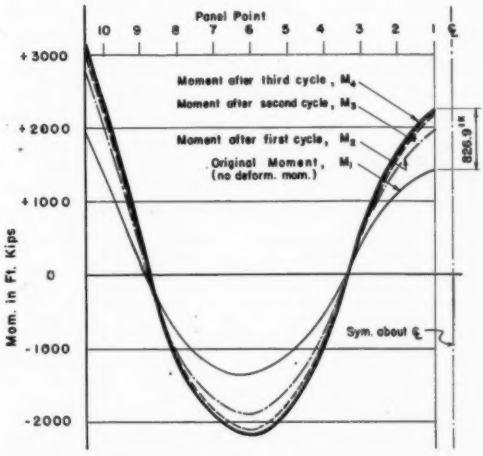


Fig. 1—Total moment, including moment due to rib deflection

TABLE 2—DEFLECTION MOMENTS—LOADING FOR MAXIMUM POSITIVE MOMENT AT CROWN

PT	M	N	Wc	Vc	Mc	Δ_1	Mo-1	M_1 +28.883 H_1y	ΔM_1	M2	Wc	Vc	Mc	Δ_2
E		+1110.3		0				-732.1 0				0		
1	+1432.6	+1111.2	+1680.6	+1680.6	+164,712	+1.1438	+1270.1	+3.8	+541.8	+1974.4	+2316.2	+2316.2	208,621	+1.4488
2	+1116.4	+1119.0	+1257.2	+2937.8	+139,000	.9653	+1081.2	33.2	+382.3	+1498.7	+1687.7	+4003.9	173,186	1.2027
3	+477.7	+1134.4	+514.9	+3452.7	+94,055	.6532	+741.0	92.2	+101.1	+578.8	+623.9	+4627.8	111,930	.7773
4	-474.1	+1152.8	-488.3	+2964.4	+41,232	+.2863	+330.0	181.2	-220.9	-695.0	-715.8	+3912.0	41,129	.2856
5	-1082.8	+1169.6	-1061.4	+1903.0	-4,120	-.0286	-33.5	301.4	-464.2	-1547.0	-1516.5	+2395.5	-18,721	-.1300
6	-1352.7	+1190.2	-1262.9	+640.1	-33,233	-.2308	-274.7	453.0	-553.8	-1906.5	-1779.9	+615.6	-55,369	-.3845
7	-1260.0	+1213.3	-1116.0	-475.9	-43,027	-.2988	-362.5	637.6	-457.0	-1717.0	-1520.7	-905.1	-64,787	-.4499
8	-797.5	+1239.2	-665.1	-1141.0	-35,746	-.2482	-307.6	856.4	-183.3	-980.8	-818.1	-1723.2	-50,940	-.3537
9	+76.0	+1269.2	+59.7	-1081.3	-18,290	-.1270	-161.2	1111.5	+218.2	+294.2	+231.1	-1492.1	-24,577	-.1707
10	+1364.0	+1307.7	+852.9	-228.4	-1,747	-.0121	-15.8	1404.4	+656.5	+2020.5	+1263.4	-228.7	-1,749	-.0121
S	+1918.7	+1330.8			0		0	1565.6	+833.5	+2752.2			0	0

PT	Mo-2	M_2	H_1y	ΔM_2	M_3	Wc	Vc	Mc	Δ_3	Mo-3	M_3 +38.735 H_1y	ΔM_3	M_4
E		-866.1	0				0				-915.1 0		
1	+1609.9		+4.7	+748.5	+2181.1	+2558.6	+2558.6	+225,098	+1.5632	+1737.0	+5.0	+826.9	+2259.5
2	+1345.8		41.5	+521.2	+1637.6	+1844.1	+4402.7	+185,954	1.2913	+1445.0	44.5	+574.4	+1690.8
3	+881.8		115.3	+131.0	+608.7	+656.1	+5058.8	+118,138	.8204	+930.7	123.6	+139.2	+616.9
4	+329.2		226.6	-310.3	-784.4	-807.8	+4251.0	+40,744	.2829	+326.1	243.0	-346.0	-820.1
5	-152.0		376.9	-641.2	-1724.0	-1690.0	+2561.0	-24,292	-.1687	-197.3	404.2	-708.2	-1791.0
6	-457.6		566.5	-757.2	-2109.9	-1969.8	+591.2	-63,473	-.4408	-524.6	607.5	-832.2	-2184.9
7	-515.9		797.4	-614.6	-1874.6	-1660.3	-1069.1	-72,517	-.5036	-611.0	855.2	-670.9	-1930.9
8	-438.3		1071.0	-233.4	-1030.9	-859.8	-1928.9	-56,162	-.3900	-483.3	1148.5	-249.9	-1047.4
9	-216.7		1390.0	+307.2	+383.2	+301.0	-1627.9	-26,651	-.1851	-234.9	1490.6	+340.6	+416.6
10	-15.8		1756.2	+874.3	+2238.3	+1399.6	-228.3	-1,746	-.0121	-15.8	1883.4	+952.5	+2316.5
S	0		1957.9	+1091.8	+3010.5			0		0	2099.7	+1184.6	+3103.3

Where; (1) M & N are the initial elastic Moments and Thrusts obtained from the loading combination of 1.2 (D + 2L)
(2) Δ_1, Δ_2, ... Δ_3 are the successive deflections
(3) Wc, Vc, and Mc are the conjugate weights, shears, and moments respectively
(4) ΔM_1, ΔM_2, ΔM_3 are the successive moments caused by the increasing deflection
(5) M_1, M_2, and M_4 are the total Moment after each successive cycle.

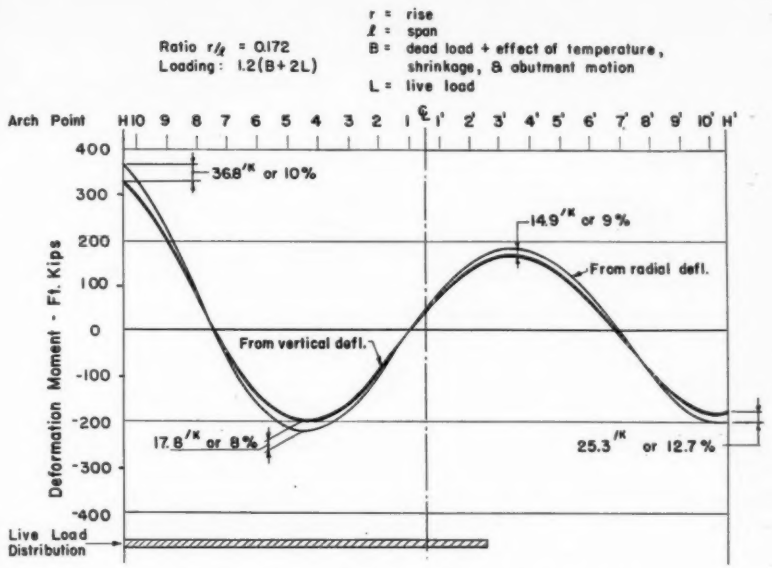


Fig. 2—Effect of lateral displacements on deformation moment

points and new values of yds/EI, $y^2\ ds/EI$ and $M'\ yds/EI$. For the case of arches with a low rise-span ratio these variations may be neglected without introducing excessive errors.

(c) Computations including horizontal as well as vertical deflections would be similar to those of Table 2, but deformations due to rib shortening must be included in the evaluation of horizontal deformations to have the end conditions check. As shown by Fig. 2 the error caused by neglecting horizontal deflections is small. The added computations may be neglected for arches whose rise-span ratio is less than one to five.

(d) Since the relationship between the deflection moments and the individual loads is not linear it is important to select load combinations, *i.e.*, factors in Eq. (1) and (2) leading to a reasonable value of the total thrust. The influence of the load combination on deflection moments is exemplified in the two curves of Fig. 3, in which curve *a* gives the deflection moments obtained by using a standard specification, *i.e.*, using Eq. (2) with the same coefficient of safety for dead and live load. Curve *b* gives the deflection moments due to the thrust produced by loads $1.2(B + 2L + W/2)$. In this curve the dead load (and hence the important dead load thrust) was given a safety increase of 20 percent; an allowance which should be completely adequate provided the deflection moments are included in the analysis.

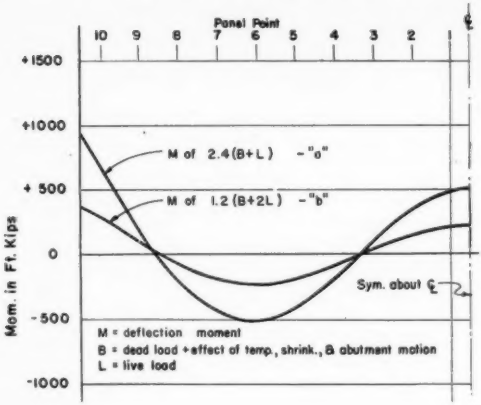


Fig. 3—Influence of load combination on deflection moments

(e) The maximum economy is obtained by choosing a rib stiffness producing a minimum value of the total moments. The parts of the total moment depending upon the stiffness of the rib are those caused by volume changes, abutment motion and deflection. Fig. 4 illustrates a typical variation of these moments with the rib stiffness. The optimum stiffness, giving a minimum total moment, is represented by point m on the curve $c + d$. The recommended procedure for calculating deflection moments will automatically correct the stiffness for ribs of less than the optimum stiffness, *i.e.*, for overflexible ribs. In fact, overflexible ribs will produce high deflection moments, requiring greater rib strength and hence automatically increase the size of the rib or the percentage of reinforcing steel, with consequent increase in rib stiffness, decrease in deflection and decrease in total moment.

If instead the selected rib is too stiff, the moments will be greater than at m and these greater moments will appear to require an increase in the rib strength with a consequent increase in rib stiffness, leading to greater moments and hence to a cyclic and uneconomical increase in rib strength.

(f) The total rib moments, as also seen from Fig. 4, depend not only on the moment of inertia, but on the modulus of elasticity of the concrete. The modulus of elasticity cannot be evaluated with great accuracy, since the effective modulus of the section will vary due to lack of uniformity in the materials, to variations in mix and in moisture content, and also depending on duration and intensity of the stresses. Due to the variation in stress alone, the effective modulus of elasticity for a 4000 psi concrete may vary from 4,500,000 psi at normal working stresses to 1,000,000 psi for stresses near the ultimate strength of the section.

Moreover, stresses of long duration produce plastic flow in the concrete with an effect equivalent to a drop in the effective modulus. Accordingly, in the analysis of structures with high dead load moments, lower values of the modulus of elasticity should be chosen than for structures subjected

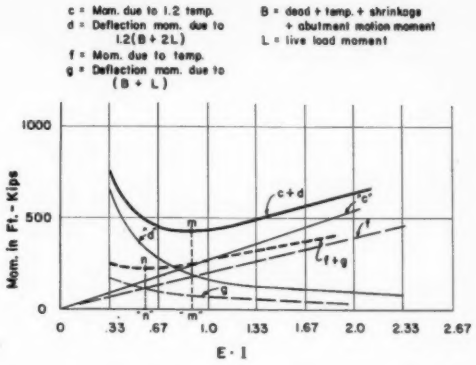


Fig. 4—Variation of moments with rib stiffness

largely to loads of short duration. Until further studies of existent long span structures are made, conservative values of the modulus should be chosen. For example, 4,000,000 psi may be taken for volumetric changes and 2,000,000 psi for the determination of deflection moments and stability.

(g) The determination of the rib stiffness requires the evaluation of the moment of inertia of the composite section. In ribs with large thrust values, cracking will affect only small parts of the total rib length and the full concrete section, including the transformed steel area, may be used, assuming a value of $n = 10$ for the steel. When large portions of the rib are subject to cracking or plastic flow, the steel plays a more important part in the resistance of the section and n should be assumed greater than 10. In this case, ribs with a higher percentage of steel are more reliable than poorly reinforced sections. For example, an increase of 1 percent in the steel percentage which would increase the moment of inertia by approximately 18 percent for $n = 10$ would cause an additional increase in the moment of inertia of 45 percent if $n = 30$. It is therefore recommended that a minimum of 1 percent of reinforcing steel be used for all important arches.

(h) It is recommended that in the design of reinforced concrete arches the ultimate strength of concrete members be evaluated by the methods developed and described in the 1940 report of Committee 312, which have been proved simple and adequate.

The plasticity of concrete under high stresses or under stresses of long duration also results in a redistribution of the moment between sections. The amount of this moment redistribution depends on the intensity of the stress, the duration and rate of application of the loads and on the redundancy of the structure. The factors affecting the plastic redistribution of stress are too many and too indeterminate to allow use of this property in the design of concrete arches, but it may, in certain cases, offset errors in proportioning and inaccuracies in design assumptions.

Discussion of a report of Committee 312:

Plain and Reinforced Concrete Arches*

By O. GRUENWALD and P. RONGVED, HUBERT RUSCH, C. H. GRONQUIST, ANTON TEDESKO and COMMITTEE

By O. GRUENWALD† and P. RONGVED†

The committee's report is an interesting contribution to the literature on the design of plain and reinforced concrete arches. The writers have been concerned with this phase of structural engineering for many years and can, therefore, well appreciate the extent of the committee's work in preparing their report. The writers believe that certain aspects of arch analysis have been overemphasized and, perhaps, needlessly complicated, while other aspects have been lightly treated to the point where the suggested procedure may lead to a dangerous structure. It is the latter subject which the writers wish to briefly review in this discussion.

The committee recommends that the effects of plastic flow may be allowed for by a simple reduction in the modulus of elasticity of the concrete without particular regard to the buckling stability of the arch being designed. The committee's example gives 4,000,000 psi for volumetric changes and 2,000,000 psi for computation of deflection moments and stability.

The writers have extended Dischinger's‡ work giving Fig. A, which shows the deformation moments as a function of rib stiffness and plastic flow. The curves for $\phi = 0$ are based on a completely elastic material uninfluenced by plastic flow. The second set of curves for $\phi = 4$ indicate a concrete in which the ultimate plastic deformation is four times as great as the elastic deformation for the same loading. The two sets of curves show the variation in moment at the crown and at the springing line. Naturally this work could be extended to give a complete family of curves at other critical sections of the arch.

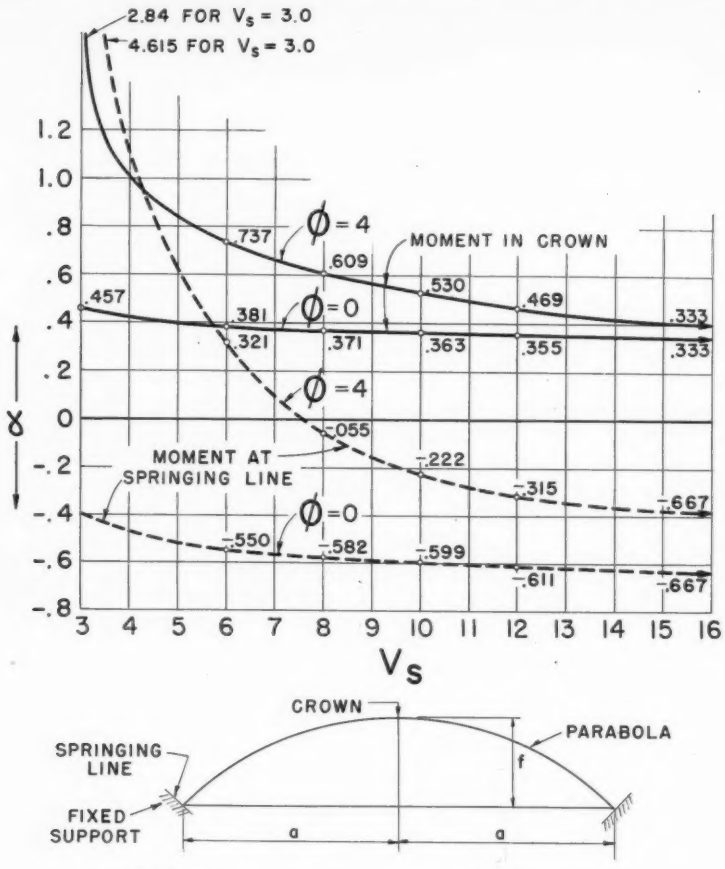
Fig. A defines the safety factor against symmetrical buckling. The committee makes no specific recommendations as to acceptable safety factors against buckling. It is possible that in using the committee's curve for optimum rib stiffness that the arch falls in a stability range where plastic flow can be completely underestimated if one follows the committee's suggestion.

For example, if a given arch with an assumed effective modulus of 4,000,000 psi has a safety factor of six against buckling, the deformation moment for

*ACI JOURNAL, May 1951, *Proc.* V. 47, p. 681. Disc. 47-46 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 23, No. 4, Dec. 1951, *Proceedings* V. 47.

†Engineer of Design and Senior Structural Engineer, respectively, Roberts and Schaefer Co., New York, N. Y.

‡Dischinger, F., "Untersuchungen über die Knicksicherheit, die elastische Verformung und das Kriechen des Betons bei Bogenbrucken," *Der Bauingenieur*, 1937.



$V_s = \frac{33.21\ E\ I}{H\ a^2}$ SAFETY FACTOR AGAINST SYMMETRICAL BUCKLING

$M = \alpha\ H_e\ f$, DEFORMATION MOMENTS

H = HORIZONTAL THRUST

H_e = REDUCTION IN HORIZONTAL THRUST DUE TO RIB SHORTENING

ϕ = A RATIO OF PLASTIC TO ELASTIC DEFORMATION

E = EFFECTIVE MODULUS OF ELASTICITY

I = MOMENT OF INERTIA

Fig. A—Deformation moments, M, as a function of rib stiffness and plastic flow

$\phi = 0$ has a factor equal to 0.381. By assuming that the effective modulus is equal to 2,000,000 psi the deformation moment would be comparable to that indicated for half the safety factor, three, giving a deformation moment factor of 0.457. On the other hand, if the plasticity index of the concrete is 4, the deformation factor would be 0.737, or approximately 60 percent greater than that indicated by reducing the effective modulus by half. The above example was taken for the curves giving moment in the crown of the arch. At the springing line the effect would be considerably more and the moment would actually change in sign.

The example assumed a basic safety factor of six. While the significance of plastic flow may be appreciable depending upon the plasticity index it nevertheless is not too critical in this region. However, if one chooses an arch cross section which gives an arch with a lower basic factor of safety against buckling, the effects of plastic flow become relatively more significant and the designer must give the most serious consideration to the possible extent of plastic flow. At a factor of safety of 3 for a given value of ϕ the crown moment may be increased 600 percent and the springing line moment 1100 percent over the deformation moments for $\phi=0$. While the curve is not extended to safety factors below 3 a reduction of 50 percent in the effective modulus would only increase the deformation moments approximately 50 percent or less. One may argue that $\phi = 4$ is an unreasonable index to choose. On the other hand, observations of important structures have shown fairly substantial deformations due to plastic flow.

The writers, therefore, recommend that the committee give serious attention to the effects of plastic flow, particularly with respect to those slender arches where safety factor against symmetrical buckling is lower than six.

By HUBERT RUSCH*

The proposed calculation procedure apparently is based on the following thoughts.

1. The influence of the arch deformation on the internal stresses must not be neglected.
2. Because of the nonlinear relationship between loads and deflection moments, it is not sufficient to determine the stresses due to the working loads, but is also necessary to determine the stresses for ultimate load.
3. Due to the variation in uncertainties regarding various loads, it is necessary to introduce safety factors of various values to determine the ultimate load.

Based on the above thoughts, the committee proceeded in a commendable manner and presented detailed information for the preparation of calculations. It seems to the writer that it is first necessary to check the soundness of the basic ideas.

INFLUENCE OF ARCH DEFORMATION ON THE INTERNAL FORCES

Dischinger, among other authors, has investigated this subject in great detail. His paper† is especially interesting because it shows the laws relating

*Professor of Structures and Head of Government Materials Research and Testing Laboratory, Institute of Technology, Munich.

†Dischinger, F., "Studies of Buckling Stability and Deformation of Concrete Arches, etc.," *Der Bauingenieur*, V. XVIII, 1937, No. 33-34, pp. 487-520; No. 35-36, pp. 539-552; No. 39-40, pp. 595-621.

the moments to the static system, buckling safety, plastic flow, etc. It further shows how the moments can be determined quickly by the use of a converging series.

It can be seen from Dischinger's paper that deformation moments are of important influence only for arches of small buckling safety and for arches which do not follow the pressure line for dead load. It further shows that fixed arches are less subject to deformation moments than hinged arches. Designers, in most cases, will avoid such constructions for a variety of reasons and the deformation moments will therefore only in very exceptional cases be of such influence that a special calculation of the stresses due to deflection moments will be required.

NECESSITY FOR CALCULATION OF ULTIMATE LOADS

The deformation moments grow more rapidly than the increasing load. This could be taken care of by increasing somewhat, by a certain factor, the deformation moments due to the working load. This factor could easily be determined with the use of the series of the Dischinger paper.

When the arch is to be examined for a load, which has been multiplied by a safety factor, the assumption of a constant modulus E is no longer sufficient. The modulus may decrease considerably in the vicinity of the highest stressed portions of the arch causing a very substantial redistribution of the interior forces in statically indeterminate arches as well as a release of the stresses in the previously endangered sections.

The calculation of the ultimate load under the assumption of a constant modulus E therefore represents an inaccurate idealization of the actual conditions. The advisability of such a calculation must be in doubt. The writer will show that this approach also does not seem to be the most logical way to establish the desired safety of a structure.

PURPOSE AND SIZE OF SAFETY FACTORS

Safety factors are chosen for a structure to compensate for the existing uncertainties. These uncertainties may be due to the following causes.

Uncertainty in assumption of loading

This uncertainty is usually taken care of in the choice of the size of the loads. Usually the loads are assumed in a manner to cover the most unfavorable expected load combinations. The dead load of the construction materials can usually be determined without difficulty and with sufficient accuracy. The live load is usually chosen high enough to take care of developments in respect to future increase of loads. The highest values of wind and snow loads in various locations are used. An arch for which the loads were carefully determined likely will not be overloaded. It is much more likely that the actual dead loads will be less than the assumed design values. Paradoxically this condition may lead to an increase of the stresses at certain sections due to change in position of the actual thrust line.

Inaccuracies in the basis for the calculation

The following inaccurate assumptions have to be mentioned hereunder: the assumption of a constant E, the magnitude of the chosen E, the assumptions of fixity or freedom at the hinges, the nonconsideration of the stiffness of the superstructure and inaccuracies in the assumed laws of creep. All are in reality only rough idealizations of the actual conditions.

Uncertainty in assumed strength of materials

One cannot be certain that the actual structure contains concrete and steel of the strength, modulus of elasticity and creep characteristics used in the calculations.

Inaccuracies in construction

This includes deviations from the theoretical shape of the arch, also local deficiencies of the material, such as honeycombing of the concrete and poor welding of splices of the steel, temperature stresses due to the hardening process of the concrete and influence of the settlement of the form centering.

Errors in calculations

Besides certain unavoidable inaccuracies in the calculations, there is always the possibility of undisclosed errors.

Selection of safety factor

Only the uncertainties in assumption of loading are a function of the loads and the writer mentioned previously that it would be more logical to compensate for these uncertainties by the proper choice of load assumptions.

The question arises whether the assumed maximum loads can occur at the same time. There is no doubt that it is most unlikely that the heaviest live load on a bridge will occur at the time of maximum wind load. On the other hand, it is quite possible that such maximum loads will occur simultaneously in buildings in which arch ribs form a part of the structural system. Maximum wind and snow loads on roofs in most cases may not occur at the same time. When combining most unfavorable loads only "possible" conditions are to be investigated. Here it may be taken into consideration that stresses under certain loading conditions, such as due to movement of supports, will decrease with time.

Considering that the loading uncertainties have been taken care of by proper load assumption, as is common practice, then the factor of safety must be chosen having the same value for all loading conditions because the other uncertainties are independent of the character of the load.

A safety factor should never be selected on the premise that the structure should be or is capable of supporting an ultimate load equal to the working load times the factor of safety. Rather, the choice of an adequate factor of safety should be based on the assumption that the before-mentioned uncertainties may be additive under unfavorable circumstances and may lead to working load stresses higher than calculated for certain sections of the structure where the material strength may happen to be smaller than anticipated. The safety factor then prevents a failure in the critical sections.

It may be concluded that the nonlinear relationship between loads and deformation moments is not of such great importance as assumed in the committee report. Only a part of the mentioned uncertainties can lead to a more than linear increase of these moments.

SUMMARY

1. The factor of safety is not to serve for the compensation of load increases, but only for the compensation of uncertainties which under the influence of the working loads may endanger certain sections where increased stresses may coincide with insufficient strength of the material.

2. After the loads are correctly chosen the factor of safety must be the same for all loading conditions because the existing uncertainties are in all cases of the same nature.

3. The term "ultimate load" may clarify the picture, but is often misleading. This concept should be used only under certain conditions. It is not recommended for use in connection with arch design.

4. After the compilation of the most unfavorable load conditions only probable load combinations should be investigated. It should be investigated in each individual case whether maximum live load, wind load and snow load can possibly occur simultaneously.

5. Stresses due to certain load conditions will be altered considerably in the first years after completion of the structure, due to the influence of creep. It is necessary in such cases to combine the most unfavorable load conditions, both for the condition at the beginning and at the completion of the creep period.

6. Creep decreases stresses due to shrinkage considerably. Concrete of high shrinkage always has a high creep. It can be proved, therefore, that due to creep the final shrinkage stresses in an arch are almost independent of the amount of shrinkage and can be figured sufficiently exact with a shrinkage coefficient equal to 1.5×10^{-4} whereby the effect of creep in the calculations can then be neglected.

7. The influence of the movement of the supports under normal conditions is reduced by the creep to a fraction of the value calculated on the basis of the elastic theory.

8. The deformation moments are considerably increased by creep. This influence must not be neglected in those cases where deformation moments are considerable.

9. For arches shaped according to the pressure line but having a substantial buckling safety, the deformation moments are usually so small that it is not necessary to complicate the calculations by their inclusion. Moreover, existing theoretical papers make it easy to estimate the size of the deformation moments.

10. When the nonlinear relationship between loads and deformation moments is to be considered, this, in view of the real meaning of the safety factor, must not be done for loads multiplied by the full value of the safety factor. This influence, however, is best taken care of by an assumed increase in the deformation moments.

11. The influence of the bending moments must not be neglected in the calculation of the buckling safety. The buckling safety of an arch is decreased in extraordinary strong measure by the bending moments. Moments due to movement of support, temperature, and volume changes are not of the same category as the moments due to live loads. Sufficient buckling safety, as called for in paragraph 9, is the factor of safety of buckling determined under consideration of the influence of the moments. This influence can be determined from existing test values for reinforced concrete columns (see tests by Baumann, Zurich) or from the buckling theory (Engesser). The new German code for the calculation of arch bridges contains a simple calculation method for the solution of this problem.

By C. H. GRONQUIST*

The authoritative report of this committee is a definite, forward-looking contribution to the literature on concrete arches. A design procedure based on ultimate strength calculated with the use of factors of safety that differ in accordance with type of loading is a logical development which should be generally adopted.

With the increasing use of high strength concrete and relatively flexible construction in roofs and other arches, the effect of deflection becomes important in the design of concrete arches. The method of successive approximations employed by the committee to compute the increase in moment due to deflection is practicable and has been used for this purpose in connection with the design of steel arches. It is laborious and time-consuming, however, especially when several different loading conditions must be investigated.

The fact that the modulus of elasticity of concrete is subject to great variation and that uncertainties always exist as to load and physical characteristics of the structure would indicate that approximation in the computation of the deflection effect is certainly warranted, particularly when different rib proportions and loading conditions must be investigated. An approximate method for computing the correction for deflection effect in steel arches previously described by the writer,† can be applied equally well to concrete arches. Since the effect of horizontal deflection is usually negligible for fixed arches, the correction is made for vertical deflection only.

The percentage of correction for deflection effect is equal to the ratio of dead plus live load thrust to the final buckling load computed for a strut of length equal to the distance between points of counterflexure and having a moment of inertia equal to that at the crown of the arch. For half-span loading the distance between points of counterflexure is about $3/8L$ and the correction for vertical deflection is:

$$\frac{H_w + H}{\frac{64}{9} \times 9.6 \frac{EI_c}{L^2} - (H_w + H)} = \frac{H_w + H}{P_f}$$

This correction is applied to the moments computed by the ordinary method neglecting deflection. Moments computed for a 0.42-span loading producing maximum moment near the quarter point would be corrected with the use of the distance between the points of counterflexure for that load condition, or about $0.32L$. The moment at the crown for a 0.3-span loading would be corrected with the use of the $0.31L$ distance between points of counterflexure. The actual percentage of correction for any loading is fairly constant along the length of rib, but decreases somewhat near the springing line due to the greatly increased stiffness there.

The moments produced by wind loading may be corrected in the same manner as for vertical loading. Although the deflections of the arch pro-

*Associate Engineer, D. B. Steinman, Consulting Engineer.

†Discussion, "Rainbow Arch Bridge over Niagara Gorge, A Symposium," *Transactions*, ASCE, V. 110, 1945, pp. 150-159.

duced by temperature and shrinkage are affected little by correction for deflection effect, the value of the thrust is modified. This produces a correction in the moments as usually computed, but the correction is comparatively minor.

The deflection correction in the moment for combined loading, including temperature, live load and wind multiplied by the appropriate factors of safety, would be equal to the ratio of the combined thrust to the final buckling load computed for the distance between the points of counterflexure for the combined loading. Application of the approximate correction to the ordinary moments computed for the combined loading conditions would provide an expeditious means of evaluating with sufficient precision the final combined deflection effect.

By ANTON TEDESKO*

The authors can be commended on this clear presentation of a design procedure for ultimate load covering a subject on which the senior author consistently has made valuable contributions. It is always important to point out the influence of secondary moments, such as deflection moments which are of special concern to the designer of slender arches. The outlined calculation procedure can be used for the design of slender arches. The writer questions, however, the advisability of advocating the proposed procedure as a standard guide for the general use of the profession.

The committee report would be considerably enhanced if some data were included showing when the deformation moments become important. On this subject Dischinger in several papers† presented a procedure which is based on the intimate relationship existing between deflection moments and the factor of safety against buckling. This relationship was referred to in a previous discussion by the writer.‡ One significance of Dischinger's work is that the arch designer can predetermine with reasonable accuracy whether the slenderness employed is within the range where deflection moments may affect the safety of the arch. If a sufficient§ arch stiffness (or a sufficient safety factor for buckling) is chosen for an arch which is shaped to follow the pressure line of the load, it is unnecessary in most cases to make an elaborate analysis and to provide for moments due to deflections. This approach in some respects resembles that used in thin-slab analysis where dimensions may be determined by the general practitioner without resorting to time consuming calculations based on an exact theory.

Unless the designer chooses an unusually slender arch, he will generally find that neglecting the nonlinear relationship in the increase of secondary moments introduces no greater errors in his design than neglecting the variation of modulus of elasticity from section to section. The effective modulus

*Engineer-Manager, Structural Dept., Roberts and Schaefef Co., Chicago, Ill.

†Dischinger, Franz, "Untersuchungen über die Knicksicherheit etc.," "Elastische und Plastische Verformungen etc." (containing investigations on arch stability, arch deformations, both elastic and inelastic), *Der Bauingenieur*, 1937, p. 487-621; 1939, p. 53-572.

‡Tedesko, Anton, Discussion of "Long-Span Concrete Arches," ACI JOURNAL, Dec. 1950, *Proc.* V. 46, p. 416-1.

§Indefinite terms, such as "sufficient, slender, relatively low, etc.," are used herein to avoid quoting large portions of the Dischinger paper. These terms are employed here with the meaning attached by Dischinger.

for the ultimate load condition may vary considerably throughout the arch as the stresses vary, depending upon how close the stresses come to the ultimate. It is therefore questioned whether the adoption of the concept of ultimate load in arch design offers advantages except under special conditions.

The committee report would gain by comments on arches whose axes do not follow the thrust line. In every day practice these arches are predominant and offer economical solutions. The writer's company has conducted extensive research on the question of arch economy which showed the extent to which the width-depth ratio, rise-span ratio and shape affect the arch cost. An entire series of economic relationships existing for arches of one given span and method of support will change significantly with a change of any of the basic premises. An answer as to optimum economy, especially in building construction, cannot be given in a simple sentence. For example, if an arch is supported by vertical columns, it could easily be possible in the case of fairly high columns that it is cheaper to reduce column stiffness and induce arch bending moments than to increase column stiffness and minimize arch bending moments. Furthermore, experience has shown that the most slender arch which can be built may not be the most practical and economical, especially if field conditions and rapid all-weather construction are considered. The writer would therefore accept with reservation the committee's statement that maximum economy is achieved when total arch moments are a minimum.

The committee's report provides useful information to the experienced arch designer who can critically judge its limitations. The writer well appreciates the complexity of the authors' subject matter and wishes to commend them for their interesting presentation.

COMMITTEE'S CLOSURE

Committee 312 wishes to thank the discussers for their comments and interest in the report on plain and reinforced concrete arches. The committee has considered the suggestions in detail and wishes to make no changes in its recommendations. It does wish, however, to emphasize some of the points in the report which have been questioned.

The design principles stated are general and apply to concrete arches regardless of their shape or the nature of their supports. It is not believed that arches whose axes do not follow the pressure line (excluding frames from consideration) are either predominant or good practice unless their form is dictated by special conditions. The elasticity of supports should always be considered in design calculations.

Because the dimensions of arches and their supports are determined largely by the total moments they are subjected to, it appears reasonable to expect that a reduction in moments will reduce cost.

Full consideration has been given to the effect of plastic flow, creep, variations in modulus of elasticity, and other factors which cannot be precisely

evaluated. The value 2,000,000 psi suggested for use as the effective modulus E in estimating deflection moments combines the effects of permanent dead load, temporary live loads and the influence of reinforcing steel. It is therefore greater than the equivalent modulus for plain concrete as effected by plastic flow under long time loading. The suggested value is consistent with observations on completed structures.

It is recommended that each of the above factors be considered separately and reasonable limiting values be assumed. Accurate methods of calculating the combined effects of such factors and the loads should be used instead of approximate methods which permit compounding of errors.

The committee does not approve the use of a factor of safety with a single set of coefficients as proposed by Professor Rüsch. One limiting equation of the committee report is of this type (Eq. 2a and 2b). A more severe condition often occurs using combinations having less than the maximum coefficients for some of the factors. Furthermore, design and code loads do not always represent the maximum possible loads applied during the life of the structure and certain of these are likely to vary much more than others. For these reasons a second limiting equation (Eq. 1a and 1b) is necessary for the design of the rib to cover critical combinations.

The committee does not believe that the roughly approximate methods for computing the deflection stresses suggested by several discussers should be used to estimate the total deflection moments for concrete arch ribs though such methods may be useful, as mentioned by Mr. Gronquist, for arriving at the preliminary proportions of the arch rib. Total moments must include the *simultaneous* effect of displacements due to plastic flow; creep, shrinkage, cracking and abutment motion as well as those due to live load moments and thrust. The displacement moments of long-span arches due to causes other than live load are a large part of the total moments. The proposed methods of analysis permit evaluation of the different factors to any degree of accuracy desired and show which effects are important and need particular investigation.

The use of a buckling factor higher than the factor of safety against overstress is meaningless. As Dr. Dischinger pointed out in the paper quoted by several discussers, long-span structures have failed although the theoretical buckling stability factors were high. Furthermore, while deflection moments will decrease with increased rib stiffness, the volumetric and rib displacement moments will increase due to the same stiffness. Instead of increasing the buckling factor the commiteee recommended the use of conservative values for the modulus, E, the minimizing of conditions which aggravate the buckling condition, and the use of sufficient reinforcing steel to control long time deflection of the arch. The report goes a step further in recommending that certain minimum displacements should be applied to the arch at an overload condition to make sure the arch will recover and will carry the consequent moments in the deflected position without becoming unstable. As the arch rib will fail when the total moments, including the buckling moments exceed the moment and thrust capacity of the rib, greater safety, if desired, should

be obtained by increasing the over-all factors of safety rather than by increasing the buckling factor of safety beyond that indicated by the proposed recommendations.

As shown by observations and measurements of a number of long-span structures, the minimum rib dimensions permitted by the recommendations of this report will not result in lack of economy or delay in the decentering of the rib.

Title No. 47-47

While further test and experimentation are necessary to determine most effective and economical additives to cement, the authors' findings indicate that alkali-aggregate expansion may be thus prevented.

New Approach to Inhibiting Alkali-Aggregate Expansion*

By W. J. McCOY† and A. G. CALDWELL‡

SYNOPSIS

Investigators have studied for a decade the chemical reactions between high-alkali cement and siliceous mineral constituents of some aggregates toward deterioration of concrete. Papers on this subject indicate a consensus that there are just two possible remedial measures when reactive aggregates are used—low-alkali cement or substitution of a pozzolanic material for 20 to 30 percent of the portland cement.

Investigative work focused off the beaten path of pozzolans and lowering cement alkali content resulted in experimental data which indicate that small amounts of certain materials added to high-alkali cement have an inhibiting effect on expansion reaction. For example, it has been found that 1 percent or less of specific salts will reduce expansion more than 75 percent in Pyrex glass mortar bar tests. This reduction was substantiated by similar mortar bar tests using a small percentage of opal and quartz sand as aggregate.

Additional information indicates that small amounts of certain proteins (0.2 percent or less) added to the cement appear to have a greater inhibiting effect on the expansive reaction than is obtained by comparable air entrainment effected by the conventional air-entraining agents.

Such inhibitors appear to have no appreciable detrimental effect on the properties of the high-alkali cements as determined by ASTM specification tests for cement.

INTRODUCTION

The alkali-aggregate problem in concrete has had nationwide attention since 1940 when Thomas E. Stanton published two papers[1,2] explaining that excessive expansion of concrete can be caused by chemical reactions between cements of relatively high alkali content and some rocks and minerals in aggregate. Because these papers offered plausible reason for instances of

*Presented at the ACI 47th Annual Convention, San Francisco, Calif., Feb. 22, 1951. Title No. 47-47 is a part of the copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 22, No. 9, May 1951, *Proceedings* V. 47. Separate prints are available at 50 cents each. **Discussion** (copies in **triplicate**) should reach the Institute not later than Sept. 1, 1951. Address 18263 W. McNichols Rd., Detroit 19, Mich.

†Member American Concrete Institute, Director of Research, Lehigh Portland Cement Co., Coplay, Pa.
‡Research Chemical Engineer, Lehigh Portland Cement Co., Coplay, Pa.

expansion and deterioration of concrete in California that had previously defied explanation, considerable interest was aroused among users and producers of portland cement and aggregate and other laboratories began investigating this problem.

It was soon reported[3-7] that other concrete structures in Arizona, Idaho, Kansas, Nebraska, Virginia, Washington and Wyoming had deteriorated due to alkali-aggregate reaction, accompanied by a decline in strength, significant expansion and development of pattern cracking. In 1944, W. C. Hansen[8] suggested that this expansion was caused by osmotic pressures within alkalic silica gels. Hansen's theory was substantiated by a detailed investigation conducted by McConnell, Mielenz, Holland and Greene[9] showing that concrete destruction arises from osmotic imbibition of water by alkalic silica gels formed through interaction between the aggregate and the alkalies liberated by the high-alkali cement during hydration. These osmotic pressures exceed the tensile strength of the concrete and cause fractures which probably are sufficiently extensive to account for the increase in volume and the decline in strength.

The above authors[9] conclude that since the majority of the cracks originate at the reactive aggregate grains and pass radially outward, the fractures are the result of stresses originating at the aggregate grains themselves. Parsons and Insley[10] also substantiated Hansen's hypothesis but they concluded that the cracks originate from gel-filled pores and not at the reactive aggregate grains.

An excellent summary of the status of studies of alkali-aggregate reaction was made by William Lerch[11] in 1950. According to Lerch these studies have, in large part, been directed toward developing methods of test for aggregates to determine their potentialities for producing abnormal expansion and pattern cracking when used with high-alkali cements, and methods of minimizing or avoiding this expansion and pattern cracking. The approaches now available toward minimizing or avoiding such deterioration are the selection of a nonreactive aggregate, the use of low-alkali cement, and the use of certain proved pozzolanic admixtures.

INHIBITED ALKALIES

It is not uncommon for traces or small amounts of certain substances to exert an inhibiting effect on a given chemical reaction. A classic example is the inhibiting effect of an impurity such as oxygen on the chain reaction of hydrogen and chlorine in the presence of light to form hydrogen chloride. Most of us are perhaps more familiar with materials such as rust inhibitors designed to inhibit or restrain oxidation associated with the rusting of metals. A more pertinent example is that no less than five patents[12] were granted recently to the Wyandotte Chemicals Corp. for methods of producing inhibited alkalies for use in cleaning glass surfaces or methods of inhibiting the attack on glass surfaces by caustic soda. One illustration given in U. S. Patent No. 2,419,805[12] is that small amounts of beryllium oxide fused with sodium hy-

droxide will reduce the quantity of glass dissolved in glass weight loss test from 1.75 to 0.026 g. Additional information on the action of inhibited alkalies on glass is given by T. H. Vaughn, L. R. Bacon and W. F. Wegst.[13] Their test data show that in a given working test regular alkali caused a loss of 4.3 g of glass while with the inhibited alkali the loss was only 0.25 g. It seemed reasonable to expect that with adequate investigative work, collaboration among researchers and cooperative pooling of information, it would be possible to discover a material or method by which the alkalies in cement could be inhibited from reacting with the siliceous component of certain aggregates in concrete to produce excessive expansion.

MORTAR BAR TEST

The mortar bar test, the most popular tool of investigators in studying reactive combinations of cement and aggregate, has recently been adopted by ASTM as a tentative method of test for "Potential Alkali Reactivity of Cement-Aggregate Combinations" C 227-50T. This general procedure has also been extensively used by the Bureau of Reclamation as a performance test in specifications[14] for pozzolans whereby a substitution of the pozzolan for 20 to 30 percent of a high-alkali cement must effect at least a 60 to 75 percent reduction in the 14-day expansion of Pyrex glass aggregate and high-alkali cement mortar. L. P. Witte[15] has pointed out that the Pyrex glass mortar bar test appears to offer a simple means for testing the effectiveness of materials in reducing alkali-aggregate expansion.

Hanna[17] and Stanton[18] report that low-alkali cements (less than 0.5 percent Na_2O equivalent) when tested by the mortar bar test gave excessive expansion with reactive aggregates after periods of several months. However, Meissner and Blanks[19] explain this by pointing out that the extensive use of the mortar bar test for predetermining troublesome combinations of cements and aggregates has provided a large volume of data and information which show conclusively that the test does not yield results which can be used comparatively at ages beyond a few months. Expansion at later ages may be largely or entirely induced by factors wholly independent of the reactive tendencies of the particular combination of materials involved. They substantiate the above remarks by pointing out that regardless of the results of long-time mortar bar tests, it has been repeatedly demonstrated by structures in service that expansions have not been obtained with cements of low alkali content.

In view of the foregoing information the results on expansion reduction tests of Pyrex mortar bars are reported here for ages of 2, 4, 6 and 8 weeks. ASTM method C 227-50T using Pyrex glass and a high-alkali cement (Na_2O equivalent in excess of 1 percent) was followed except that a fixed water-cement ratio was employed as used by the Bureau of Reclamation for determining the effectiveness of pozzolans in reducing expansion. In some tests the water was adjusted as noted in the tables. The chemical composition of the cements is given in Table 1. Table 2 gives data on blank tests of cements and common materials.

TABLE 1—CHEMICAL ANALYSIS AND CALCULATED COMPOUND COMPOSITION OF CEMENTS USED IN EXPANSION BAR TESTS REPORTED IN TABLES 2 TO 9

Cement	A	B	C	D	E	F
Type	I	I	I	I	III	I
Percent						
SiO_2	22.1	21.3	21.8	21.8	20.2	21.4
Al_2O_3	6.3	5.7	5.6	6.1	5.5	5.7
Fe_2O_3	2.8	3.4	3.2	2.5	2.1	2.4
CaO	61.1	61.4	60.1	63.3	63.7	63.2
MgO	3.1	4.2	4.5	3.0	3.6	2.5
SO_3	2.1	1.9	2.2	1.8	2.8	1.8
K_2O	0.90	0.70	0.79	0.37	0.33	0.85
Na_2O	0.66	0.68	0.72	0.32	0.19	0.15
Ig. loss	1.3	1.1	1.3	1.1	1.5	2.2
Total	100.4	100.4	100.2	100.3	99.9	100.2
Percent						
Na_2O Equiv.	1.25	1.15	1.24	0.57	0.41	0.71
C_3S	29	40	31	42	58	48
C_2S	42	31	40	31	14	25
C_3A	12.0	9.3	9.6	12.1	10.9	11.1
C_4AF	8	10	10	8	6	7

TEST RESULTS

Tables 3 to 9 show expansion test data obtained when small amounts of various materials were added to high-alkali cement Pyrex glass mortar bars in the search for an inhibitor.

These data are the average of results obtained on two specimens except in the case of the blanks which are the average of at least six specimens. Close examination of the data in these tables will show that occasionally the actual expansion values for two different materials may not be consistent with the reduction in expansion values. This is because different blank cements were used in fabricating the specimens. The test numbers show that the data have been rearranged from a chronological order to a system based on the nature of the addition being tested.

Some rather significant indications are shown in Tables 3-9. Some substances caused a reverse effect and increased expansion. Those increasing expansion included barium carbonate, calcium and ferric chlorides, nickel nitrate, powdered antimony, the acetates of ammonium, lead and zinc, adipic

TABLE 2—BLANK TESTS OF MATERIALS USED IN INHIBITOR STUDIES—PYREX GLASS MORTAR BARS

Test No.	Material	Expansion, percent				Reduction in expansion, percent			
		2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
	Cement A-1	.178	.236	.283	.295				
	Cement A-2	.245	.343	.364	.363				
	Cement B	.298	.451	.500	.538				
	Cement C	.202	.270	.306	.312				
226	Cement C with 25 ml less water	.138	.169	.177	.178	32	37	42	43
228	Cement C, reg. water plus 25 ml	.204	.316	.417	.456	−1	−17	−36	−46
259	Cement C, 48 hr fog cure	.280	.348	.383	.388	−39	−29	−25	−24
260	Cement C, 24 hr fog plus 24 hr 50 percent humidity	.023	.080	.107	.114	89	70	65	63

TABLE 3—EFFECT OF METALS AND METALLIC SALTS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Material	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent (−means expansion incr.)			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
192	*Al* (powder)	0.25	B	.071	.096	.113	.134	76	79	77	75
180	*Al* (powder)	1.0	B	.080	.120	.164	.176	73	74	67	67
55	Al_2O_3	2.0	A-1	.156	.248	.292	.296	12	− 5	− 3	0
77	*Al* stearate	1.0	A-2	.206	.242	.244	.246	16	29	33	32
238	$Al_2(SO_4)_3 \cdot Na_2SO_4$	1.0	C	.202	.254	.294	.300	0	6	4	4
247	$BaAl_2O_4$	1.0	C	.184	.252	.300	.306	9	7	2	2
107	$BaCO_3$	1.0	B	.381	.532	.598	.679	−28	−18	−20	−26
164	$BaCO_3$	1.0	B	.294	.441	.482	.521	1	2	4	3
122	$Ba(OH)_2$	1.0	B	.312	.484	.580	.612	− 5	− 7	−16	−14
106	$BaSO_4$	1.0	B	.311	.450	.528	.616	− 4	0	− 6	−14
123	BaS_2O_3	1.0	B	.326	.508	.618	.652	− 9	−13	−24	−21
121	*Ba* soap	1.0	B	.244	.388	.450	.486	18	14	10	10
7	$BeSO_4$	0.05	A-1	.184	.222	——	——	− 3	6	—	—
6	$BeSO_4$	0.1	A-1	.144	.223	.273	.315	19	6	4	7
15	$BeSO_4$	0.2	A-1	.186	.201	.236	.246	− 4	15	17	17
87	*Ca* aluminate	1.0	A-2	.220	.309	.324	.324	10	10	11	11
36	$CaCl_2$	1.5	A-1	.272	.302	.376	.400	−53	−28	−33	−36
108	$CaCO_3$	5.0	B	.294	.437	.512	.576	1	3	− 2	− 7
109	$CaCO_3$	10.0	B	.283	.438	.514	.568	5	3	− 3	− 6
37	CaF_2	1.0	A-1	.182	.177	.242	.262	− 2	25	14	11
250	$CaO \cdot SiO_2$	5.0	C	.126	.173	.195	.200	38	36	36	36
95	$Ca(OH)_2$	2.0	A-2	.268	.370	.413	.408	− 9	− 8	−13	−12
96	*Ca* oleate	1.0	A-2	.153	.186	.204	.200	38	46	44	45
76	$CdSO_4$	1.0	A-2	.236	.329	.352	.346	4	4	3	5
74	$CoCl_2$	1.0	A-2	.290	.394	.436	.432	−18	−15	−20	−19
43	CrO_3	0.35	A-1	.208	.238	.300	.311	−17	− 1	− 6	− 5
167	$CrPO_4$	1.0	B	.294	.436	.473	.488	1	3	5	9
73	$Cr_2(SO_4)_3$	1.0	A-2	.207	.280	.296	.292	16	18	19	20
92	$Cu(C_2H_3O_2)_2$	1.0	A-2	.283	.405	.436	.438	−16	−18	−20	−21
71	$CuCl$	1.0	A-2	.263	.330	.340	.336	− 7	4	7	7
129	$CuCl_2$	1.0	B	.214	.334	.376	.380	28	26	25	29
128	$CuCl_2 \cdot 2NH_4Cl$	1.0	B	.254	.529	.590	.609	−19	−17	−18	−13
154	$CuCO_3$	0.1	B	.299	.412	.436	.438	0	9	13	19
70	$Cu(NO_3)_2$	1.0	A-2	.166	.245	.262	.260	32	29	28	28
126	CuO	1.0	B	.294	.414	.464	.474	1	8	7	12
127	Cu_2O	1.0	B	.274	.396	.437	.436	8	12	13	19
140	*Cu* oleate	1.0	B	.143	.191	——	——	52	58	—	—
69	$CuSO_4$	0.5	A-2	.186	.233	.242	.238	24	32	34	34
101	$CuSO_4$	0.8	A-2	.275	.309	.312	.322	12	10	14	11
54	$CuSO_4$	1.0	A-1	.050	.098	.111	.110	72	58	61	63
143	$CuSO_4$	1.0	B	.141	.266	.296	.302	53	41	41	44
125	$CuSO_4$	1.0	B	.192	.268	.287	.289	36	41	43	46
58	$FeCl_3$	1.0	B	.336	.467	.540	.557	−89	−98	−91	−89
86	$FeSO_4$	1.0	A-2	.246	.326	.356	.358	0	5	2	1
153	KCl	1.0	B	.332	.404	.410	.412	−11	10	18	23
150	$LiCl$	0.5	B	.074	.258	.328	.355	75	43	34	34
139	$LiCl$	1.0	B	.031	.042	.049	.063	90	91	90	88
149	Li_2CO_3	0.5	B	.032	.144	.166	.202	89	68	67	62
138	Li_2CO_3	1.0	B	.018	.026	.034	.049	94	94	93	91
172	LiF	0.5	B	.024	.036	.056	.094	92	92	89	82
163	LiF	1.0	B	.008	.006	.009	.009	97	99	98	98
145	Li_2SiO_3	1.0	B	.036	.094	.160	.177	88	80	68	67
137	$LiNO_3$	1.0	B	.056	.130	.344	.428	81	72	31	20
144	Li_2SO_4	1.0	B	.035	.129	.236	.282	88	72	53	48
38	$MgSiF_6$	1.0	A-1	.177	.194	.266	.324	1	18	6	−10
117	$MgSO_4$	1.0	B	.334	.480	.574	.614	−12	− 6	−15	−14
75	$MnSO_4$	1.0	A-2	.221	.290	.307	.302	10	15	16	17
168	*Na* alginate	1.0	B	.265	.414	.470	.539	11	8	6	0
225	$Na_2Al_2O_4$	1.0	C	.142	.170	.182	.184	30	37	41	41
39	$NaBF_4$	1.0	A-1	.140	.167	.229	.268	21	29	19	9
152	$NaCl$	1.0	B	.360	.438	.452	.456	−21	3	10	15
151	Na_2CO_3	1.0	B	.256	.297	.301	.304	14	34	40	44
277	Na_2CO_3	1.5	C	.143	.176	.178	.177	29	35	42	43
148	$Na_3Co(NO_2)_6$	1.0	B	.390	.623	.730	.732	−31	−38	−46	−36
56	$NH_4(C_2H_3O_2)$	1.0	A-1	.286	.472	.571	.575	−61	−100	−100	−95

TABLE 3—EFFECT OF METALS AND METALLIC SALTS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS—Continued

Test No.	Material	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent (−means expansion incr.)			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
23	NH_4Cl	1.0	A-1	.240	.282	.324	.327	−35	−20	−14	−11
165	$(NH_4)_2CO_3$	1.0	B	.210	.300	.322	.335	30	34	36	38
41	$(NH_4)_2C_2O_4$	1.0	A-1	.178	.190	.260	.288	0	19	8	2
42	$(NH_4)_2Cr_2O_7$	1.0	A-1	.160	.188	.247	.259	10	20	13	12
194	NH_4OH	2.0	B	.220	.310	.371	.391	26	31	26	27
40	$(NH_4)_2SO_4$	1.0	A-1	.150	.170	.222	.236	11	28	22	20
24	NH_4 stearate	2.0	A-1	.107	.132	.150	.158	40	44	47	46
72	$NiNO_3$	1.0	A-2	.300	.412	.466	.465	−22	−20	−28	−28
159	$Pb(C_2H_3O_2)_2$	1.0	B	.455	.580	.593	.630	−53	−29	−19	−17
246	$PbCO_3$	0.5	C	.222	.284	.306	.310	−10	− 5	0	1
160	$PbCrO_4$	1.0	B	.330	.451	.461	.470	−11	0	8	13
177	$Pb(NO_3)_2$	0.5	B	.381	.427	.453	.491	−28	5	9	9
176	PbO	0.5	B	.339	.385	.422	.458	−14	15	16	15
18	Sb (powder)	1.0	A-1	.224	.312	.352	.362	−26	−32	−24	−23
22	$SbCl_3$	0.2	A-1	.190	.209	——	——	− 7	11	—	—
189	$SnCl_2$	1.0	B	.292	.442	.528	.608	2	2	− 6	−13
135	$SrCl_2$	1.0	B	.327	.494	.575	.598	−10	−10	−15	−11
134	$SrCO_3$	1.0	B	.245	.366	.442	.470	18	19	12	13
133	$Sr(NO_3)_2$	1.0	B	.212	.328	.397	.432	29	27	21	20
136	$SrSO_4$	1.0	B	.311	.407	.462	.472	− 4	10	8	12
16	Zn (powder)	0.5	A-1	.240	.285	.299	.308	−35	−21	− 6	− 4
17	Zn (powder)	1.0	A-1	.168	.212	.242	.248	6	10	14	16
57	$Zn(C_2H_3O_2)_2$	0.1	A-1	.227	.335	.378	.380	−28	−42	−34	−29
173	$ZnCO_3$	0.5	B	.282	.321	.338	.354	5	29	32	34
132	Zn oleate	1.0	B	.306	.416	.457	.468	− 3	8	9	13
4	$ZnSO_4$	0.1	A-1	.136	.230	.253	.300	24	3	11	2
3	$ZnSO_4$	0.2	A-1	.180	.210	——	——	− 1	11	—	—
14	$ZnSO_4$	0.3	A-1	.164	.224	.256	.262	8	5	10	11

and lactic acid, phenol and triethanolamine. Particular attention is called to the fact that calcium chloride is in this group since it is frequently added to concrete mixes to accelerate strength gain.

The materials which appear to be the most effective in reducing expansion resulting from the alkali-aggregate reaction are copper sulfate, the lithium salts, and gas-entraining substances such as aluminum powder, various proteins and proprietary A-E agents. Perhaps the most outstanding results are those for the lithium salts (Table 3). This group almost without exception showed expansion reductions greater than obtained with any of the other metallic salts. The protein air-entraining agents (Table 7) also seemed to be particularly effective in reducing expansion. Considerable work has been reported in the literature regarding aluminum powder but it does not appear satisfactory as a gas-forming agent for the purpose of expansion reduction because of the difficulty of controlling the amount of entrained gas.

It is emphasized that in many cases the effect of these various materials on alkali-aggregate expansion is based on a single percentage addition. This does not necessarily mean that a similar effect would be obtained if more or less was added. It is not within the scope of this paper to test all the materials mentioned at all possible percentages but the data presented demonstrate the effect of the material when added in the quantity mentioned.

To further check on the effectiveness of copper sulfate and lithium carbonate as inhibitors to alkali-aggregate expansion, a few tests were made using

TABLE 4—EFFECT OF ACIDS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Acid	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent			
				2 wk	4 wk	6 wk	8 wk	4 wk	4 wk	6 wk	8 wk
62	Adipic	1.0	A-1	.421	.584	.662	.658	−72	−70	−82	−81
81	Arsenious	1.0	A-2	.201	.280	.293	.292	18	18	20	20
67	Benzoic	1.0	A-1	.268	.349	.384	.383	− 9	− 2	− 6	− 6
33	Boric	1.0	A-1	.108	.120	.146	.151	39	49	48	49
206	Cresylic	1.0	B	.320	.473	.560	.608	− 7	− 5	−12	−13
237	Lactic	1.0	B	.263	.362	.455	.495	−30	−34	−49	−59
131	Linolic	1.0	B	.204	.284	.332	.341	32	37	34	37
78	Mucic	0.1	A-2	.213	.290	.302	.302	13	15	17	17
31	Oleic	1.0	A-1	.058	.066	.084	.090	67	72	71	70
34	Oxalic	1.0	A-1	.130	.156	.218	.248	27	34	23	16
32	Palmitic	1.0	A-1	.092	.099	.120	.127	48	58	58	57
35	Pyrogallic	0.1	A-1	.122	.140	.190	.216	31	41	33	27
171	Silicic	1.0	B	.383	.451	.487	.538	−29	0	3	0
64	Stearic	1.0	A-1	.228	.278	.288	.285	7	19	21	21
146	Sulfanilic	1.0	B	.283	.450	.520	.540	5	0	− 4	0
80	Tannic	0.1	A-2	.257	.364	.384	.384	− 4	− 6	− 6	− 6
79	Tartaric	0.1	A-2	.148	.240	.267	.271	40	30	27	25
66	Titanic	1.0	A-2	.239	.328	.346	.344	3	4	5	5

mortar bars fabricated with standard Ottawa sand (1:1 mix of 20-30 and graded) containing 2½-in. minus 30 mesh opal. The mortar contained two parts by weight of aggregate to one of cement and was made up to a 100-115 flow using ASTM Method C 109-49, Section 9. The data obtained in this series of tests (Table 10) are averages of duplicate determinations. The same size specimen and the same storage conditions were employed as for the Pyrex bar tests.

These test results confirm the findings of the Pyrex glass mortar bar tests in that 1 percent of lithium carbonate appears to have an appreciable inhibiting effect on alkali-aggregate expansion. Copper sulfate which appeared to offer some promise in the Pyrex glass tests does not look favorable as an inhibitor in the opal bar tests. Had these inhibitors been tested with the cement used in test 8-A the results would no doubt be much more impressive. Fig. 1 illustrates the excessive expansion caused by the addition of 2½ percent minus 30 mesh opal to Ottawa sand and also how this excessive expansion can be inhibited by the addition of 1 percent lithium carbonate (basis of cement).

TABLE 5—EFFECT OF OILS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Oil	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
97	Castor	1.0	A-2	.274	.359	.398	.394	−12	− 5	− 9	− 9
88	Cocoanut	1.0	A-2	.226	.274	.284	.287	8	20	22	21
89	Cottonseed	1.0	A-2	.244	.310	.322	.325	0	10	12	10
231	Fish	1.0	C	.186	.228	.248	.258	8	16	19	17
98	Linseed	1.0	A-2	.250	.313	.344	.341	− 2	9	6	6
190	Pine	1.0	B	.306	.454	.544	.584	− 3	− 1	− 9	− 9
115	Soy bean	1.0	B	.193	.317	.374	.396	35	30	25	26
90	Turkey red	1.0	A-2	.161	.225	.233	.232	34	34	36	36

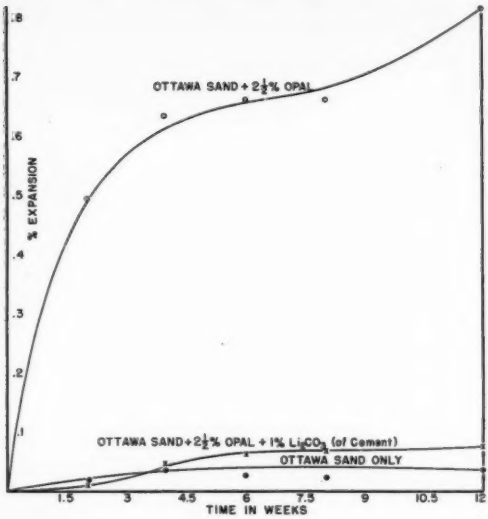


Fig. 1—Expansion of Ottawa sand—high-alkali cement (Na_2O equiv. 1.25) mortar bars

As previously pointed out some of the protein additions in the Pyrex glass mortar bar test (Table 8) appear to offer promise as expansion inhibitors. When this group of Pyrex mortar bars was being fabricated it could readily be observed that some air was being entrained which is known to have a beneficial effect on reducing alkali-aggregate expansion. To obtain further data on these additions, bars were fabricated from mortar as prepared for ASTM test method C 185-49T and the inhibitors were added in amounts to entrain 20-21 percent air—the top range of air content for A-E cements as given in ASTM specification C 175-48T. Two and one-half percent of minus 30 mesh opal was added to the sand. Expansion tests were conducted to compare the two most promising inhibitors in this group with two of the

TABLE 6—EFFECT OF ORGANIC CHEMICALS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Material	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
201	Acetone	1.0	B	.170	.324	.424	.454	43	28	15	16
202	Amyl alcohol	1.0	B	.188	.352	.470	.510	37	22	6	5
158	Ethyl silicate	1.0	B	.258	.350	.360	.369	13	22	28	31
179	Glycerine	1.0	B	.336	.456	.550	.558	−13	− 1	−10	− 4
236	Glyceryl monostearate	1.0	C	.174	.221	.244	.248	14	18	20	20
104	Gum arabic	0.25	B	.317	.458	.519	.590	− 6	− 2	− 4	−10
157	Methyl cellulose	1.0	B	.180	.232	.246	.260	40	49	51	52
191	Methyl cellulose	2.0	B	.100	.144	.181	.218	66	68	64	60
239	Naphthalene	1.0	C	.206	.260	.312	.326	− 2	4	− 2	− 4
83	Phenol	0.5	A-2	.388	.493	.534	.534	−58	−44	−47	−47
141	Guanidine carbonate	0.5	B	.368	.500	.558	.562	−23	−11	−12	− 4
208	Saccharin	0.5	B	.210	.324	.400	.434	30	28	20	19
99	Triethanolamine	1.0	A-2	.348	.530	.633	.682	−42	−54	−74	−88
82	Urea	0.5	A-2	.249	.356	.374	.374	− 2	− 4	− 3	− 3

TABLE 7—EFFECT OF PROPRIETARY COMPOUNDS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Material	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
8	Activated clay	1.0	A-1	.248	—	—	—	−39	—	—	—
9	Activated clay	2.0	A-1	.198	.296	—	—	−11	−25	—	—
10	Activated clay	5.0	A-1	.184	.238	.264	.281	− 3	− 1	7	5
20	Activated clay	10.0	A-1	.234	.288	.300	.306	−31	−22	− 6	− 4
249	A-E agent (ASTM agent A)	0.1	C	.064	.091	.118	.128	68	66	61	59
261	A-E agent (ASTM agent A)	0.1	C	.094	.141	.164	.176	54	48	46	44
268	A-E agent (ASTM agent C)	0.1	C	.104	.148	.169	.177	48	45	45	43
270	A-E agent (ASTM agent C)	1.0	C	.086	.134	.158	.172	57	50	48	45
230	Hydrolyzed protein (adjusted water, 25 ml less)	0.25	C	.094	.102	.102	.102	54	62	67	67
214	Hydrolyzed protein	0.5	C	.098	.144	.174	.198	51	47	43	37
215	Hydrolyzed protein (adjusted water, 15 ml less)	0.5	C	.056	.077	.093	.102	72	71	70	67
219	Hydrolyzed protein (adjusted water, 25 ml less)	0.5	C	.054	.066	.073	.074	73	76	76	76
209	Hydrolyzed protein	1.0	B	.095	.140	.202	.239	68	69	60	56
210	Hydrolyzed protein (adjusted water, 15 ml less)	1.0	B	.067	.083	.106	.117	78	82	79	78
203	Ion-exchange resin A	1.0	B	.290	.416	.504	.532	3	8	− 1	1
204	Ion-exchange resin B	1.0	B	.266	.416	.511	.563	11	8	− 2	− 5
217	Plasticizer	1.0	B	.170	.222	.246	.254	16	18	20	19
218	Plasticizer (adjusted water, 15 ml less)	1.0	B	.122	.158	.165	.166	40	41	46	47
274	Set retarder	0.25	B	.214	.285	.336	.371	− 6	− 6	−10	−19
187	Silicone A	1.0	B	.286	.384	.484	.559	4	15	3	− 4
188	Silicone B	1.0	B	.298	.394	.496	.579	0	13	1	− 8
170	Sulfated slag cement	5.0	B	.259	.380	.390	.405	13	16	22	25
169	Water softener (precipitant)	1.0	B	.304	.410	.435	.460	− 2	9	13	14
273	Water softener (sequestrant)	1.0	B	.258	.322	.358	.377	−28	−19	−17	−21
53	Wetting agent	0.5	A-1	.155	.254	.296	.296	13	− 8	− 5	0

regular ASTM approved A-E agents. These tests were run in duplicate with the same size specimens and storage conditions as the Pyrex bar tests. These data (Table 11) demonstrate that air entrainment does significantly reduce alkali-aggregate expansion and also that for a given air content some A-E agents are more effective than others.

AIR ENTRAINMENT

Digressing from laboratory studies, consider the potential benefits of air entrainment on the alkali-aggregate reaction. For example, after rather extensive study and numerous inquiries it was not possible to learn of a single case of excessive expansion known to be caused by the alkali-aggregate reaction when A-E cement was used or an A-E agent was added at the mixer. This may be of little significance since air entrainment is a recent development and has not been commonly used where reactive aggregates occur. However, because some A-E agents are more effective in reducing alkali-aggregate expansion than others the possibilities of this rather simple solution to the

TABLE 8—EFFECT OF PROTEINS ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX MORTAR GLASS BARS

Test No.	Material	Addition, percent	Cement	Expansion, percent				Reduction in expansion, percent			
				2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
124	Albumin, blood	0.10	B	.082	.123	.153	.166	72	73	69	69
263	Albumin, blood	0.15	C	.044	.066	.076	.086	78	76	75	72
105	Albumin, blood	0.25	B	.077	.110	.153	.190	74	76	69	65
222	Albumin, blood (adjusted water, 25 ml less)	0.10	C	.036	.045	.050	.051	82	83	84	84
267	Albumin, egg	0.25	C	.060	.080	.092	.102	70	70	70	67
265	Albumin, egg (Esh's cpd.)	0.5	C	.150	.217	.246	.252	26	20	20	19
103	Casein	0.25	B	.084	.116	.161	.200	72	75	68	63
221	Casein (adjusted water, 25 ml less)	0.25	C	.034	.044	.050	.051	83	84	84	84
93	Casein	0.5	A-2	.068	.076	.092	.092	72	78	75	75
266	Dextrose	0.1	C	.120	.160	.183	.185	41	41	40	40
229	Fish glue (adjusted water, 25 ml less)	0.25	C	.062	.072	.078	.084	69	73	75	73
220	Fish glue (adjusted water, 25 ml less)	0.5	C	.032	.044	.054	.058	84	84	82	81
216	Fish glue	1.0	C	.056	.088	.114	.144	72	67	63	54
235	Gelatine	1.0	C	.101	.142	.168	.210	50	47	45	32
240	Gluten, wheat	1.0	C	.046	.067	.086	.106	77	75	72	66
205	Animal protein A	0.25	B	.094	.144	.176	.188	68	65	65	65
223	Animal protein A (adjusted water, 25 ml less)	0.25	C	.049	.060	.066	.068	76	78	78	78
248	Animal protein B	0.25	C	.042	.064	.086	.096	79	76	72	69
255	Animal protein B	0.1	C	.098	.138	.159	.183	52	49	48	41
174	Soy bean meal	0.5	B	.095	.116	.138	.153	68	74	72	72
178	Starch	0.1	B	.316	.390	.429	.466	− 6	14	14	13
147	Zein	1.0	B	.174	.292	.370	.376	42	35	26	30

problem do not appear to have been studied adequately. Most laboratory testing for alkali-aggregate expansion is conducted under greatly accelerated conditions of reactivity. Under these conditions excessive expansions can be obtained with cements having less than 0.6 percent alkali and with aggregates known to have satisfactory service records. By the same token the beneficial

TABLE 9—EFFECT OF CHEMICAL MIXTURES ON EXPANSION OF HIGH-ALKALI CEMENT—PYREX GLASS MORTAR BARS

Test No.	Mixture	Cement	Expansion, percent				Reduction in expansion, percent			
			2 wk	4 wk	6 wk	8 wk	2 wk	4 wk	6 wk	8 wk
185	0.25% Albumin + 0.5% $CaCl_2$	B	.100	.150	.194	.208	66	67	61	61
184	0.25% Casein + 0.5% $CaCl_2$	B	.196	.277	.342	.364	34	39	32	32
186	1.0% $CuSO_4$ + 1.0% $CaCl_2$	B	.280	.433	.509	.517	6	4	− 2	4
183	0.25% Li_2CO_3 + 0.25% $CuSO_4$	B	.120	.235	.312	.349	26	48	38	35
181	0.5% LiF + 0.5% $CaCl_2$	B	.022	.032	.043	.054	93	93	91	90
182	0.25% LiF + 0.25% Li_2CO_3	B	.037	.057	.096	.128	88	88	81	76
193	0.1% LiF + 0.25% Li_2CO_3	B	.051	.102	.163	.217	83	78	67	60
196	0.1% + 0.2% Albumin + 0.5% $CaCl_2$	B	.062	.124	.178	.226	79	73	64	58
195	0.1% LiF + 0.2% Casein + 0.5% $CaCl_2$	B	.130	.218	.294	.350	56	52	41	35
198	0.05% LiF + 0.1% Li_2CO_3 + 0.2% Albumin + 0.5% $CaCl_2$	B	.051	.110	.170	.228	83	76	66	56
197	0.05% LiF + 0.1% Li_2CO_3 + 0.2% Casein + 0.5% $CaCl_2$	B	.084	.154	.212	.258	72	66	58	52
200	0.25% Li_2CO_3 + 0.25% Albumin + 0.5% $CaCl_2$	B	.070	.132	.205	.270	77	71	59	50
199	0.25% Li_2CO_3 + 0.25% Casein + 0.5% $CaCl_2$	B	.084	.157	.240	.308	72	65	52	43

TABLE 10—EXPANSION OF 1:2 OTTAWA SAND MORTAR BARS WITH 2½ PERCENT MINUS 30 MESH OPAL

Test No.	Cement	Addition	Expansion, percent				
			2 wk	4 wk	6 wk	8 wk	12 wk
1-A	B (Na_2O equiv. 1.15 percent)	Blank—No opal	.018	.036	.029	.028	.036
2-A	B (Na_2O equiv. 1.15 percent)	No inhibitor	.498	.638	.660	.666	.812
3-A	B (Na_2O equiv. 1.15 percent)	1.0 percent $CuSO_4$	.218	.333	.378	.388	.546
4-A	B (Na_2O equiv. 1.15 percent)	1.0 percent Li_2CO_3	.014	.042	.065	.070	.073
5-A	B (Na_2O equiv. 1.15 percent)	0.5 percent Li_2CO_3	.189	.426	.496	.504	.505
6-A	D (Na_2O equiv. 0.57 percent)	No inhibitor	.010	.018	.024	.030	.072
7-A	E (Na_2O equiv. 0.41 percent)	No inhibitor	.004	.011	.011	.017	.024
8-A	F (Na_2O equiv. 0.71 percent)	No inhibitor	.014	.091	.196	.296	.688

effects of A-E agents showing considerable expansion reduction should not be summarily dismissed because after considerable time at abnormally continuous high temperature and saturated humidity a rich mortar expands more than can be tolerated for concrete under climatic conditions.

TESTS WITH REACTIVE SANDS

Samples of two different sands with known reactivity records, namely, Kimball sand (Kimball, Neb.) and Saticoy sand (Ventura County, Calif.) were obtained and tested for reactivity with a high-alkali cement (Na_2O equivalent 1.24 percent) by ASTM method C 227-50T. Parallel tests were made with the addition of 1 percent lithium carbonate (basis of cement content) and 0.1 percent blood albumin to determine the expansion reduction characteristics of the two materials with these natural reactive sands. Tests were also made on a nonreactive pure commercial quartz sand (Lilesville, N. C.) with the same high-alkali cement. The tests have not progressed far enough to furnish conclusive data although lithium carbonate appears to be exerting an inhibiting effect on the expansion similar to that obtained in the opal and Pyrex glass bars. For example, at the end of three months the nonreactive Lilesville sand specimens had an expansion of 0.03 percent, the reactive Kimball sand specimens had an expansion of 0.26 percent but the Kimball sand with the lithium carbonate had an expansion of only 0.04 percent. The blood albumin did not appear to be as effective as in previous tests but this might be because, according to the unit weight of the bars, the expected air entrainment was not obtained.

TABLE 11—EXPANSION OF ASTM C 175-48T MORTAR BARS WITH 2½ PERCENT MINUS 30 MESH OPAL AND TYPE I CEMENT (Na_2O EQUIV. 1.24 PERCENT)

Test No.	Addition	Air, percent	Expansion, percent				
			2 wk	4 wk	6 wk	8 wk	12 wk
1-B	None (blank)	10.2	.020	.093	.278	.696	.842
2-B	Blood albumin, 0.065 percent	20.2	.016	.017	.022	.030	.037
3-B	Animal protein B, 0.035 percent	20.2	.014	.017	.024	.038	.232
4-B	ASTM agent A, 0.02 percent	20.1	.014	.015	.023	.055	.200
5-B	ASTM agent B, 0.06 percent	20.6	.014	.018	.026	.154	.386

TESTS WITH LOW-ALKALI CEMENTS

An additional series of Pyrex bar tests by ASTM method C 227-50T was conducted with three cements, D, E and F, which have alkali contents of 0.57, 0.41 and 0.71 percent Na_2O equivalent respectively. The effect of the addition of 1 percent sodium carbonate and 0.72 percent of lithium carbonate (chemically equivalent to 1 percent Na_2CO_3) on the expansion of cement D, which experienced the greatest expansion of the three cements, was also determined (Table 12).

Although lithium is considered to be an alkali metal the data (Table 12 and Fig. 2) show that lithium carbonate has a reverse effect on expansion to that of an equivalent amount of sodium carbonate.

ASTM specification tests for portland cement were conducted on Type I cement with and without 0.1 percent blood albumin and with and without 1 percent lithium carbonate. These additions had no appreciable effect on the physical properties of the cement except that in the case of the 1 percent lithium carbonate addition the 1-, 3- and 7-day compressive strengths tended to be higher than the blank cement and the 28-day strength tended to be lower. In the case of the 0.1 percent blood albumin addition, the air content as measured by ASTM method C 185-49T was increased from 8.4 to 21.7 percent. The decrease in compressive strength appeared to be less than when a similar quantity of air is entrained by the addition of a conventional A-E agent.

CONCLUSION

No claim is made that the addition of lithium salts or other inhibitors is the answer to the alkali-aggregate expansion problem. These materials may be too expensive for practical use in concrete. However, their remarkable effect in reducing expansion caused by the alkali-aggregate reaction does demonstrate the value of additions of small amounts of non-air-entraining materials.

It has also been found that impressive expansion reductions can be obtained by the use of certain protein air-entraining agents. The extent of expansion reduction obtained for a given air content varies from one air-entraining agent to another.

TABLE 12—EXPANSION OF ASTM C 227-50T PYREX BARS WITH CEMENTS OF VARYING ALKALI CONTENT; EFFECT OF Na_2CO_3 AND Li_2CO_3

Cement	Expansion, percent			
	2 wk	4 wk	6 wk	8 wk
E (Na_2O equivalent 0.41 percent)	.042	.114	.154	.169
F (Na_2O equivalent 0.71 percent)	.050	.096	.118	.126
D (Na_2O equivalent 0.57 percent)	.096	.195	.242	.243
D + 1 percent Na_2CO_3	.224	.352	.364	.374
D + 0.72 percent Li_2CO_3	.009	.016	.018	.020

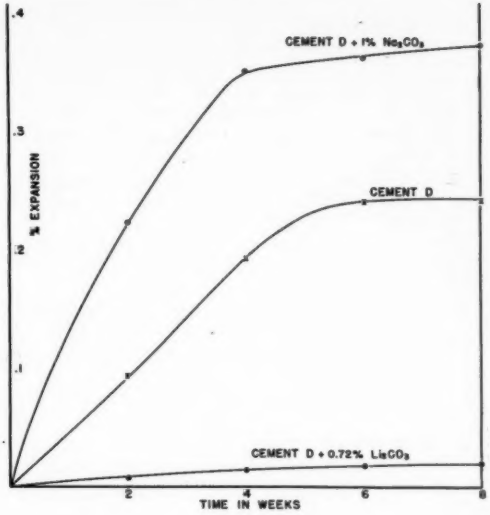


Fig. 2—Effect of equivalent amounts of sodium carbonate and lithium carbonate on expansion of Pyrex glass bars with cement D (Na_2O equiv. 0.57)

This research work has demonstrated that there is a third practical approach to the alkali-aggregate problem besides the classical methods of lowering the alkali content of the cement and the use of large quantities of pozzolanic materials. Insufficient work has been done to recommend the use of a given quantity of a specific material as an inhibitor but it is hoped that other research workers will be encouraged and stimulated to divert some of their efforts to this neglected approach to the problem. There is good reason to believe that if this approach is diligently pursued a new solution to this perplexing alkali-aggregate problem may be found.

ACKNOWLEDGMENT

Acknowledgment is gratefully made to W. W. Faust and H. P. Nicklas, members of the research staff, for fabrication and measurement of the many specimens.

BIBLIOGRAPHY

1. Stanton, Thomas E., "Influence of Cement and Aggregate on Concrete Expansion," *Engineering News-Record*, V. 124, Feb. 1, 1940, p. 59.

2. Stanton, Thomas E., "Expansion of Concrete Through Reaction Between Cement and Aggregate," *Proceedings*, ASCE, V. 66, 1940, p. 1781.

3. Meissner, Harmon S., "Cracking in Concrete Due to Expansive Reaction Between Aggregate and High-Alkali Cement as Evidenced in Parker Dam," ACI JOURNAL, Apr. 1941, *Proc.* V. 37, p. 549.

4. Kammer, H. A., and Carlson, R. W., "Investigation of Causes of Delayed Expansion of Concrete in Buck Hydroelectric Plant," ACI JOURNAL, June 1941, *Proc.* V. 37, p. 665.

5. Tremper, Bailey, "Evidence in Washington of Deterioration of Concrete Through Reactions Between Aggregates and High-Alkali Cements," ACI JOURNAL, June 1941, *Proc.* V. 37, p. 673.

6. Coombs, H. A., "Expansion of Concrete Due to Reaction Between Andesitic Aggregate and Cement," *American Journal of Science*, V. 240, 1942, p. 288.

7. Blanks, R. F., "Notes on the Effect of Alkalies in Portland Cement on the Durability of Concrete," *Proceedings*, ASTM, V. 43, 1943, p. 199.

8. Hansen, W. C., "Studies Relating to the Mechanism by Which the Alkali-Aggregate Reaction Produces Expansion in Concrete," ACI JOURNAL, Jan. 1944, *Proc.* V. 40, p. 213.

9. McConnell, Duncan C., Mielenz, R. C., Holland, W. Y. and Greene, K. T., "Cement-Aggregate Reaction in Concrete," ACI JOURNAL, Oct. 1947, *Proc.* V. 44, p. 93.

10. Parsons, W. H., and Insley, Herbert, "Aggregate Reaction with Cement Alkalies," ACI JOURNAL, Apr. 1948, *Proc.* V. 44, p. 625.

11. Lerch, William, "Studies of Some Methods of Avoiding the Expansion and Pattern Cracking Associated with the Alkali-Aggregate Reaction," *Special Publication* No. 99, ASTM, 1950.

12. Manufacture of Zincated Alkalis, U. S. Patent No. 2,403,157, July 2, 1946.
Inhibiting Alkali Dissolution of Glass, U. S. Patent No. 2,419,805, Apr. 29, 1947.
Method of Washing Glass Surfaces and Composition, U. S. Patent No. 2,425,907, Aug. 19, 1947.
Method of Inhibiting Attack on Glass Surfaces by Caustic Soda Solutions, U. S. Patent No. 2,428,187.
Protection of Glass Surface Against Alkali Attack, U. S. Patent No. 2,447,297, Aug. 17, 1948.

13. Vaugh, T. H., Bacon, L. R. and Wegst, W. F., "Bottle Scuffing Can Be Reduced," *National Carbonator and Bottler*, Sept. 1942.

14. U. S. Bureau of Reclamation Specifications for Calcined Siliceous Material for Davis Dam; Spec. No. 1904.
U. S. Bureau of Reclamation Specifications for Pozzolan for Canyon Ferry Dam; Spec. No. 2835.
U. S. Bureau of Reclamation Specifications for Pozzolan for Trenton Dam; Spec. No. 3080.
U. S. Bureau of Reclamation Specifications for Pozzolan for Cachuma Dam; Spec. No. 3172.

15. Witte, L. P., "Discussion on Chemical Reactions of Aggregate in Concrete," *Proceedings*, ASTM, V. 47, 1947, p. 1002.

16. Gilliland, J. L. and Moran, W. T., "Siliceous Admixture Specified for Davis Dam Concrete," *Engineering News-Record*, Feb. 3, 1949, p. 64.

17. Hanna, W. C., "Unfavorable Chemical Reactions of Aggregate in Concrete and a Suggested Corrective," *Proceedings*, ASTM, V. 47, 1947, p. 986.

18. Stanton, Thomas E., "Studies to Develop an Accelerated Test Procedure for the Selection of Adversely Reactive Cement-Aggregate Combinations," *Proceedings*, ASTM, V. 43, 1943, p. 875.

19. Blanks, R. F. and Meissner, H. S., "The Expansion Test as a Measure of Alkali-Aggregate Reaction," ACI JOURNAL, Apr. 1946, *Proc.* V. 42, p. 517.

ACI Standard

Recommended Practice for the Application of Mortar by Pneumatic Pressure (ACI 805-51)*

Reported by ACI Committee 805

W. L. CHADWICK
Chairman

J. A. McCRORY R. B. YOUNG

SYNOPSIS

This ACI Standard presents briefly the advantages and disadvantages of pneumatically-placed mortar and establishes recommended practices for placing and mixing shotcrete, qualifications and duties of workmen, preparation of surface before shotcreting, reinforcing, sequence of application, and other items involved in good shotcreting.

INTRODUCTION

Because of its convenience and advantages for various types of work, both for new construction and for repair and maintenance of concrete, brick, masonry and certain steel structures, there has been increased interest during recent years in the use of pneumatically-placed mortar. Mortar so placed, however, has some limitations which should be understood before decision is made to use it. For some work and conditions this material has important advantages; it is convenient, economical and structurally adequate; for other work a part or all of the advantages may be lost. It is important that the best practice be followed in application. Before stating a recommended practice, it is desirable to state the advantages and the limitations of the material to avoid, in so far as possible, misapplication of the material and disappointing results.

Definition

Pneumatically-placed mortar is mortar which is projected by an air jet directly onto the surface to which it is to be applied, irrespective of the type and manufacture of the mixing and placing apparatus. The force of the jet

*Adopted as a standard of the American Concrete Institute at its 47th annual convention, Feb. 20, 1951 as reported by Committee 805; ratified by letter ballot Apr. 5, 1951. Title No. 47-48 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 22, No. 9, May 1951, *Proceedings* V. 47. Title No. 47-48 supersedes 47-12 published in Nov. 1950. Separate prints in covers are available at 50 cents each. **Discussion** of this paper (copies in **triplicate**) should reach the Institute not later than Sept. 1, 1951. Address 18263 W. McNichols Rd., Detroit 19, Mich.

compacts the mortar in place. To avoid the cumbersome term "pneumatically-placed mortar" the word "shotcrete" is used to refer to this material in the remainder of this report.

GENERAL DESCRIPTION OF SHOTCRETING

The processing and placement of shotcrete follows these general steps:

1. Sand and cement are dry-mixed in a standard concrete mixer.
2. The dry mix is fed by gravity into a special mechanical feeder which is hereinafter referred to as a "gun."
3. Compressed air is introduced into the gun and the pressurized mix is fed out of the gun into the delivery hose by a feed wheel.
4. The pressurized dry mix passes through the delivery hose to a special nozzle. In addition to serving as an orifice, this nozzle is provided inside with a special perforated manifold through which water is introduced to the dry mix.
5. The now moistened mix jets immediately onto the object to be shotcreted.

ADVANTAGES OF SHOTCRETE

The advantages of shotcrete are:

1. It requires a relatively small, portable plant for manufacture and placement. This plant consists principally of compressed air and water sources, a standard concrete mixer for dry-mixing the sand and cement, a mechanical feeder (the gun) to feed the dry, mixed material into the delivery hose, hoses for water, air and mixed material, and a nozzle. The material hose conveys the mixed material to the point of application, replacing buckets, buggies, elevators, trucks, pumps, or similar transporting equipment which would otherwise be required. There being no heavy loads to transport, scaffolding requirements are minimum.
2. The method of placement requires a lower water-cement ratio than is normally usable with ordinary concrete placement methods.
3. The density obtained by the method of placement and the stiffness of the mix permit building up of many shapes without the use of forms; where forms are necessary, they may be considerably lighter than those usually required for concrete placement.
4. The dry mix, the method of placement and the necessity for richer mixes result in high compressive strength, and in high density for the given material.
5. Shotcrete is well adapted for use in the construction of the following works:

   New structures—Thin walls, certain roofs, slabs, Imhoff tank baffles, certain reinforced concrete tanks; linings for certain kinds of reservoirs, tunnels, sewers, shafts, canals and pipe; and work of similar extent and section.

   Coatings—Over brick, concrete, steel, masonry. (Under adverse weather conditions on deteriorated concrete surfaces and on many hydraulic

structures the durability will probably be materially less than when used on unexposed surfaces and on nonhydraulic structures.)

Encasement—Of structural steel for fireproofing and for reinforcement; of large steel pipe both inside and out; and of wooden structures for fireproofing such as in mines and some industrial buildings.

Repair—Reservoir linings, surfaces of dams under many conditions, tunnels, shafts, pipe lines, walls, tanks, sewers, canals and most of the work to which shotcrete is adapted for new work. Earthquake damage to masonry structures of all types.

DISADVANTAGES OF SHOTCRETE

The disadvantages of shotcrete are:

1. Shotcrete should be placed by skilled operators only, since both its structural value and the texture of the finished surface are greatly influenced by the skill of the workmen. Structural value and surface are also greatly affected by air pressure, sand grading, sand moisture, water use, humidity and wind.
2. The density of shotcrete is lower than the density of good concrete.
3. While shotcrete is relatively impervious to water, it is more porous than good concrete. (There appears to be evidence that this porosity is favorable to frost resistance of the shotcrete itself.)
4. Shotcrete is more subject to shrinkage cracks than concrete.
5. The natural shotcrete surface is rough and covered with rebound. This condition is objectionable for some classes of work but may be overcome by specially screeding the surface.
6. The placing of shotcrete is relatively dusty, which, with the necessity and expense for cleaning up rebound, is objectionable for some classes of work.
7. Because of the necessity of disposing of rebound clear of the work, shotcrete is applied in relatively thin layers, successive application being necessary for heavy sections.

RECOMMENDED PRACTICE

Materials

Sand—The Engineer should specify whether natural sand or sand prepared by crushing sound stone or gravel shall be used.

Grading—Sand meeting specifications for good concrete is suitable; that is, it should be graded from coarse to fine within the limits shown in the following table:

	A.S.T.M. C 33-46
Pass ⅜ sieve	100 percent
No. 4 sieve	95-100 percent
No. 16 sieve	45- 80 percent
No. 50 sieve	10- 30 percent
No. 100 sieve	2- 10 percent

Fineness modulus not less than 2.50 nor more than 3.30.

Uniformity—For the purpose of controlling the grading of fine aggregate from any one source, a preliminary sample should be submitted prior to actual delivery to the work itself. This sample should be representative of the material it is proposed to furnish. Any shipment of fine aggregate made during the progress of the work which shows a variation of fineness modulus greater than 0.20 either way from a fineness modulus of the preliminary sample should be rejected, unless by changes in proportions it may be readily made to comply with the requirements of this section.

Deleterious substances—Sand should be washed unless specific authority is granted by the Engineer to use unwashed sand. The maximum percentages of deleterious substances should not exceed the following values:

	Percent by weight
Removed by decantation	3
Shale	1
Coal	1
Clay lumps	1

The total of other deleterious substances such as mica, alkali, coated grains and soft flaky particles, should not be more than two percent by weight. The sum of the percentages of shale, coal, clay lumps, soft fragments and other deleterious substances shall not exceed five percent by weight. All sand shall be free from injurious amounts of organic impurities. When subjected to the A.S.T.M. C 40-33 colorimetric test for organic impurities, aggregates producing a color darker than the standard should be rejected.

The sand should contain three to five percent moisture at the time of mixing with cement. If the moisture exceeds five percent, the sand should be dried or allowed to drain until this maximum limit is reached.

Rebound—Rebound is sand and cement which bounces back from the surface where shotcrete is being applied, because of collision with new hard surface, reinforcement or with aggregate particles themselves. The amount varies with cement content, water use, placement angle, shape of surface, size and type of sand used, and air pressure. Because the cement content, cement condition and the fineness modulus in rebound are unpredictable, rebound should not be re-used for shotcrete.

Cement—The cement should be portland cement conforming to the A.S.T.M. specifications for Type II portland cement, Designation C 150-42, and should be subject to the same limitations as to total alkali as first-class concrete.

For volumetric batching, each bag of cement should be considered as 1 cu ft; and, for weight batching, as 94 lb.

Water—The water should be of potable quality.

Reinforcing—Depending on the thickness or extent and nature of the work, reinforcing may be either standard reinforcing steel, or fabric, or expanded metal. Fabric should be welded. Fabric or expanded metal may be self-furring, or may be used with chairs, and may be galvanized or black metal. Specifications or drawings should control each case. It should be emphasized

that the soundest shotcrete will be obtained when reinforcing is selected and designed to cause least interference with placement.

Equipment

Standard mixer—The rotating mixing equipment should be capable of thoroughly dry-mixing the sand and cement within the time available for uniformly and continuously supplying the mixed material to the gun.

Gun—The pneumatic mixing and delivering equipment most extensively used is of the vertical double-chamber type. The upper chamber receives and pressurizes the dry-mix and delivers it to the lower chamber. The lower chamber forces the pressurized mix into the delivery hose by means of a feed wheel. This type of feeder should be of sufficient capacity that the lower chamber may continuously furnish all required material to the delivery hose while the upper chamber receives the recharge.

This equipment must be kept in good condition to avoid reduced pressure and consequent reduced velocity of material delivery. The interior of the drums, feed gearing and valves should be cleaned as often as necessary (at least once every 8-hour shift) to prevent material from caking on critical parts.

Hose and nozzle—Good experience indicates that perhaps the best condition for shotcrete placement is through about 100 ft of material hose, although it is frequently necessary to use longer hose. Placing through as much as 500 ft of hose is practicable if the supply pressures are increased to maintain proper nozzle velocity. For rough or heavy work, a pressure of 50 to 60 lb is required at the nozzle. This pressure may be increased to 75 lb for high lifts or long hose to insure against clogging. Best results for finishing work are to be had when pressures of from 25 to 50 lb are used.

Equipment manufacturers recommend sufficient air pressure at the gun to produce the following material velocities for the nozzle sizes shown:

375 to 500 fps, using $\frac{3}{4}$- or 1-in. nozzles
425 to 550 fps, using $1\frac{1}{4}$-in. nozzle

The nozzles which have given the best performance are of a "pre-mixing" type, with perforated water-feed ring inside the nozzle to direct an even distribution of water through the material at the place of application. These nozzles have a lining which should be replaced when worn to the point where uniformity of material flow is lost.

Air compressor—Any standard type of compressor will be satisfactory if it is of sufficient capacity to provide, without interruption, the pressures and volume of air necessary for the longest hose delivery. In determining compressor capacity, allowance should be made for the air consumed in blowing away rebound, cleaning reinforcing and for incidental uses.

Water pump—Water pressure should be maintained approximately 15 lb higher than the highest air pressure required for placing. Both air and water pressure must be uniformly steady (nonpulsating).

Recommended procedure in placing shotcrete

The work to be done should be fully and clearly described on drawings and in specifications, all of which should be made available to the contractor or work supervisor well before any work is undertaken.

Qualifications and duties of the workmen—Because so much of the quality and satisfactory use of shotcrete depends on the skill of workmen, it is desirable that the foreman, nozzlemen and gunmen, before employment on shotcrete work, give evidence that each has done satisfactory work in similar capacities elsewhere for a sufficient period of time to be fully qualified to properly perform the work in accord with the requirements of the related specifications.

Duties of workmen—The foreman should have had good personal experience, preferably not less than two years as a nozzleman.

The nozzleman should have served a 6 months apprenticeship on similar shotcrete work and should be able to demonstrate by practical test his ability to perform satisfactorily the duties enumerated below.

1. To place the material with a minimum of water at the nozzle, but with enough to insure complete hydration and prevent excessive rebound. Normal rebound will range from 20 to 40 percent of the sand depending on the type of work and on coarseness of sand.
2. To follow a sequence or routine, in placing, which will fill corners with sound material, and cover the reinforcement with the required thickness at each layer.
3. To direct the nozzleman apprentice or helper where to clear away for the subsequent placement.
4. To hold the nozzle at the proper distance (about 3 ft except in close quarters) and at the proper angle to secure maximum compaction with minimum loss of material. This angle should be as nearly normal to the surface as the type of work permits.
5. To direct the crew when to start and stop feeding material, and to stop the work when material is not arriving uniformly at the nozzle.
6. To direct the nozzleman apprentice or helper to cut out sand or slough pockets for replacement after the surrounding shotcrete has taken its initial set. (Immediate replacement is not desirable as a rule, as it may cause additional slough in the surrounding area.)
7. To determine and insure that the air pressure at the gun is uniform and is giving proper velocity to the material at the nozzle, and that the water pressure is sufficiently (15 lb) greater than the air pressure.
8. To bring the shotcrete application to finish lines in a neat workmanlike manner.

The nozzleman apprentice should have had some good experience at similar work. He receives specific orders from the nozzleman but, in general, operates an air nozzle at and around the newly placed work to blow away all loose or porous or shattered material, to prevent its being covered in the progress of the work. Aside from his other specific duties, the nozzleman apprentice or helper helps the nozzleman with the material hose, keeping it advanced for efficient progress.

The gunman operates the mechanical feeder and directs the work of the mixer crew. Utilizing gage readings and his experience, he maintains proper

pressure (45 to 75 lb) on the pneumatic gun to provide proper nozzle velocity. His other most important duty is to assure that the material feed to the nozzle is uniform.

Preparation of the surface for application of shotcrete

Because the final structural value of a shotcrete repair depends upon its bond with the surface on which the mortar is "shot," this surface must be thoroughly cleaned and sound. Surfaces other than concrete surfaces requiring repair should also be clean, and thoroughly compacted (if earth) or well secured (if forms). All coated, scaly, or unsound concrete or masonry should be removed by chipping with pneumatically-operated gads, followed by dressing down to a sound, newly exposed surface utilizing a bush hammer or wire brush, followed by scouring with water and compressed air jet to assure removal of all loose particles. Where exposed structural or reinforcing steel is too corroded to assure a secure bond, the corrosion should be removed by sand-blasting. For this purpose, the shotcreting equipment may be used.

To facilitate bond, the cleaned surface should be moistened not more than an hour prior to placing of shotcrete. This may be accomplished with the nozzle by stopping the flow of material, then scouring the surface with an air and water jet and finally with an air jet alone to remove surplus water.

Drainage

If the surface to be shotcreted is wet from leakage, drain pipes must be placed early enough in advance of the shotcreting to entirely remove the seepage, leaving the surface in approximately the same condition as if moistened as hereinabove noted. (Where structures are subject to freezing, all leakage should be stopped before shotcrete is placed.)

Reinforcing

Reinforcing for new work that is to be shotcreted should be accurately placed in accordance with the drawings, and so well secured in position that no displacement may occur during shotcrete placement.

For repair work, standard reinforcing steel may be welded to other exposed steel within the proposed repair, or may be grouted securely into drilled holes in the common manner of placing anchor dowels. In drilling dowel holes, care should be exercised to avoid damage to existing reinforcing steel. Spacing of steel reinforcing will depend on the location, nature and extent of the repair, and should be shown by drawings. Wire mesh or fabric may be used as suited to the repair. Mesh or fabric should be anchored either by dowels grouted in drilled holes in concrete, or by secure wire ties to other steel. The full area of mesh or fabric should be held firmly in the position shown by the drawings, either by iron wire ties (No. 16 or No. 18), by wire chairs, or by other "furring" methods.

Reinforcing should not be less than $\frac{1}{2}$ in. from the surface against which the shotcrete is to be placed, and there should be not less than $\frac{3}{4}$ in. between the reinforcing and the final surface of the shotcrete.

Reinforcing steel bonds should be lapped 40 diameters. Good practice laps mesh and fabric at least one full mesh. Laps should be tied with No. 16 or No. 18 wire at 12-in. spacing.

Forms and ground wires

Wood forms, where required for support of the full weight of shotcrete, should conform in workmanship and material to supporting forms for concrete, but should be so designed as to permit the escape of placing air and rebound. Wall forms need be placed for only one side of the wall.

Adequate ground (gaging) wires should be used to establish the thickness, surface planes, and finish lines of the shotcrete.

Ground wires should be taut, secure, and true to line and plane.

Proportioning

Except for special work requiring other mixes, the mix should be one part cement to from 4 to 4.5 parts moist sand, volumetrically batch measured. With leaner mixes, the percentage of rebound increases materially.

Mixing

The minimum mixing time for each batch should be stated in the specifications but should be not less than 1½ minutes after the sand and cement are in the drum, when the drum rotates at a peripheral speed of about 200 ft per minute. Each batch should be entirely discharged before recharging is begun.

The mixer should be cleaned at regular intervals (at least once every 8-hour shift) thoroughly enough to remove all adherent material from the mixing vanes and from the drum.

No water should be added to the mix after mixing and before using in the gun. Mixed material that has stood 45 minutes without being used should be rejected. Remixing or tempering should not be permitted.

Sequence of application

Providing rebound is properly cleared away from his work, the nozzleman may work from bottom to top, or vice versa. Corners should be filled first. "Shooting" should be from an angle as nearly normal to the surface as practicable, with the nozzle held approximately 3 ft from the work (except in confined spaces where working room is cramped, where local conditions must control).

If the flow of material at the nozzle is not uniform, and slugs, sand spots, or wet "sloughs" result, the nozzleman should turn the nozzle away from the work until faulty conditions are corrected. Such defects should be cut out and repaired as the work progresses.

Shotcreting must be temporarily suspended if:

1. High wind occurs which separates the cement from the sand at nozzle;
2. Weather approaches freezing and shotcrete cannot be protected;

3. Rain, other than a very light sprinkle, occurs, otherwise cement is washed out of fresh material.

For best results, shotcrete work should be closely inspected during placement.

Time between coats

The time interval between successive applications in sloping, vertical, or overhanging work must be sufficient to allow initial, but not final, set to develop. At the time the initial set is developing, the surface should be lightly and carefully broomed to remove any laitance and provide a better bond with succeeding applications.

Construction joints

Construction joints, or day's work joints, should be sloped off to a thin, clean, regular edge, preferably at a 45-degree slope. Before placing the adjoining work, the sloped portion and adjacent shotcrete should be thoroughly cleaned as necessary, then wetted and scoured with an air jet.

Surface finish

On completing any surface, the nozzleman should bring the shotcrete to an even plane and to well-formed corners by working up to the ground wires or other thickness or alignment guides, using somewhat lower placing velocity than normal.

If screeding (or rodding) is permitted by the specifications, such work should be done with a thin-edged screed working up against gravity and by a slicing motion to trim off high and expose low spots. A thin finishing or flash coat may be applied to remove rough areas after the ground wires have been removed; or the flash coat may cover the ground wires.

If a float finish is permitted, the final surface should be lightly rubbed with a flat burlap or rubber pad, with circular or spiral motion. No hand patching should be allowed.

If a trowel finish is desired as in water channels, the steel troweling should follow careful screeding in order that wave-free smooth surfaces may be obtained with the least trowel pressure. Troweling should be done not more than one hour after placing.

Integral waterproofing

No admixture should be used unless it is impossible to obtain sufficient fines in the sand, in which case an accepted admixture up to 3 percent of the volume of cement may be used. In cases (such as hazardous tunnel and sewer lining) where a quicker set is essential than can be obtained from the use of high early strength cement, the use of calcium chloride up to 3 percent of the weight of the cement has been used successfully. The calcium chloride, if used, should be added to the mixing water in measured amounts.

Protection from severe weather

Shotcrete should not be placed on a frozen surface nor during freezing weather. As far as possible, "shooting" should be done only in weather when

it is anticipated that the temperature during the following 24 hours will not drop below 32 F.

When shotcreting must be done in freezing temperatures, a sufficiently large area to accommodate the work should be closed in by canvas or similar material, and the enclosure should be heated so that the surface to be shotcreted will be above 32 F when placing is started. The ambient temperature at the work should be maintained above 32 degrees for not less than seven days. Where placing is necessary in freezing weather, the use of high early strength cement is desirable.

Extreme heat, especially when accompanied by hot wind, will cause such quick dryout of a thin shotcrete coating that cracking and separation may be severe. Under such conditions, the shotcrete, immediately upon completion, should be covered with burlap or similar covering, which must be kept continuously moist for 14 days after shotcreting.

Curing under ordinary temperatures

As soon as the fresh shotcreted surface shows the first dry patches, a fine spray of water should be applied to keep it moist. After the surface has hardened, it should be kept moist for seven days.

When the sealing compound method of curing is used, the shotcrete surface should first be sprayed with water; then, directly after, two coats of the sealing compound should be applied. If the shotcrete is exposed to the sun, and the sealing compound is black, the application of sealing coat may be followed by one coat of whitewash.

Tests

Test cylinders should be taken so that they will represent the quality of the shotcrete being placed in the structure by each nozzleman, if more than one nozzleman is used. Each cylinder should be dated, numbered, and the name of the nozzleman noted with the stage of work in the structure.

Test cylinders should be made by shooting shotcrete into a mold of hardware cloth (¾-in. metal mesh) to make cylinders 6 in. in diameter and 12 in. long. The excess material outside the mold is trimmed off with a sharp edged trowel. The open mesh mold is used to permit the escape of air and rebound during placement and provides a cylindrical guide to trim to. About 24 hours after making the cylinders, the hardware cloth form should be removed and the cylinders stored under moist curing conditions at approximately 70 F until tested under A.S.T.M. Designation C 39-42. The tests at the age of 7 days should develop a compressive strength of not less than 3000 psi, and at 28 days not less than 4000 psi.

Measurement

For contract measurement purposes or for unit cost records, all flat work that is continuously of fairly uniform thickness should be measured by the square foot of the minimum required thickness. Irregular shaped work that has little continuity in any major direction should be computed in approximate cubic feet.

It is sometimes desirable, on irregularly shaped work, to use as a basis of payment the number of sacks of cement that have been run through the gun.

Protection of adjacent surfaces and clean-up

During progress of the work, where appearance is important, adjacent walls floors, windows, or any other parts of buildings, ornaments, or grounds which may be permanently discolored, stained, or otherwise damaged by dust and rebound, should be adequately protected and, if contacted, should be cleaned by early scraping, brushing, or washing, as the surroundings permit. Canvas covers should be placed over all equipment which may be injured by cement, dust or water. The same applies to shrubbery.

Inspection

Because of the importance of workmanship affecting the quality of shotcrete, in addition to continuous inspection during placing, all flat surfaces may be sounded with a hammer to detect inadvertent inclusion of rebound or the presence of hollow spots. Any imperfections discovered should be cut out and replaced with sound shotcrete.

Discussion of a report of Committee 805:

Recommended Practice for the Application of Mortar by Pneumatic Pressure (ACI 805-51)*

By J. M. CROM, R. M. DOULL and COMMITTEE

By J. M. CROM†

The recommendations contained in this standard apparently have been carefully considered. However, some of the statements and practices merit further discussion.

Under "Advantages of Shotcrete," it is stated, "The method of placement requires a lower water-cement ratio than is normally usable with ordinary concrete placement methods." In much shotcrete work this is not the case. The *Concrete Manual*, U. S. Dept. of the Interior, 1941 Edition, says, "The water-cement ratio of fresh Gunite in place was about 0.57 for sloping surfaces and about 0.54 for overhanging surfaces." Fresh concrete samples taken by the writer from walls had water contents ranging from 10 to 13.5 percent depending on the judgment of the nozzleman. For 1:4 mixes the water-cement ratio varied from 0.415 to 0.533 or five or six gallons of water per bag of cement. When shooting horizontal surfaces it is common to use the maximum amount of water but not to the extent that deep footprints will be made in the surface.

The addition of the extra water provides further against the trapping of excess rebound sand by reducing it and helping to incorporate it more uniformly into the mix. It is not uncommon to use 7 to 7.5 gallons of water per bag of cement and this is on the side of safety and good practice as evidenced by millions of square feet of shotcrete canal linings in Texas and Arizona and in numerous reservoirs throughout the country. It is the sand pocket that causes the trouble and not any lack of density due to too much water. Four to five thousand pound shotcrete without sand pockets is not to be compared with eight thousand pound shotcrete full of sand pockets.

The statement that "Under adverse weather conditions on deteriorated concrete surfaces and on many hydraulic structures the durability will probably be materially less than when used on unexposed surfaces and on non-hydraulic structures," should be clarified. Does it mean that the shotcrete will be materially less durable or does it mean that it may spall from the surface to which it is applied? There are many cases where shotcrete has

*ACI JOURNAL, May 1951, *Proc.* V. 47, p. 709. Disc. 47-48 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 23, No. 4, Dec. 1951, *Proceedings* V. 47.
†Vice-President, Preload Corp., New York, N. Y.

spalled after freezing but generally this has not been due to defects in the shotcrete. Shotcrete acts as a water stop and if water percolates through the body of concrete to the shotcrete and is stopped at that point cleavage will take place within the concrete or in the line of contact between concrete and shotcrete. Portions of the concrete core will generally be found adhering to the spalled shotcrete indicating that the tensile strength of the shotcrete and the joint is greater than that of the concrete to which it is bonded.

It is believed that the sentence "The density of shotcrete is lower than the density of good concrete," bears amplification. Hundreds of cylinders broken in laboratories in various parts of the country and Mexico have shown the average compressive strength of 1:4½ shotcrete to be 5000 to 10,000 psi depending on the strength of the sand. This is far above the average of usual "good" concrete. While compressive strength is not an exact measure of density it is indicative of it. Well-cured shotcrete has an absorption averaging around 3½ to 7 percent which again is an indication of its density.

It is questioned whether "Shotcrete is more subject to shrinkage cracks than concrete." During the last war a noted authority made a similar statement which was given much attention. Inquiry, however, developed that the specimen from which the data emanated was not true shotcrete. The mix had been shot into a form closed on three sides with the inevitable inclusion of laminations and sand pockets. On being questioned by the writer the authority said that the shotcrete sample beam showed a greater number of cracks than the companion concrete beam therefore the shotcrete shrunk more than the concrete. No measurements of the actual shrinkage had been made.

In 1946, Howard R. Staley and Dean Peabody, Jr.* reported that shotcrete not only does not shrink more than concrete but that its shrinkage is about 25 percent less.

Shotcrete may or may not crack more than average concrete. It has been observed that a small amount of dirt or clay in the shotcrete aggregate will have more influence on the strength and cracking of shotcrete than of concrete. If the aggregate for shotcrete is clean there should be less cracking than with concrete.

Last winter a large shotcrete job was started in Mexico City. It was proposed to place a 2-in. shotcrete lining in the 11-ft diameter masonry pipe line extending 45 miles from Lerma Springs to Mexico City. It was important that there be a minimum of cracking in the lining. The shotcrete was to be reinforced with 2 x 2-in. No. 12 wire mesh. More than 50 samples of approximately 25 sq ft each were shot, each sample containing a different kind or proportion of sand. All samples containing local sands showed excessive cracking within an hour after shooting. Some of the cracks were large enough to permit insertion of a knife blade. A satisfactory sand was finally found in the mountains 20 miles away.

*Staley, Howard R. and Peabody, Dean, Jr., "Shrinkage and Plastic Flow of Prestressed Concrete, ACI JOURNAL, Jan. 1946, *Proc.* V. 42, pp. 229-244.

Several months later it was found that sections of the lining hundreds of feet in length were without visible cracks. During the first portion of the work all of the sand was passed through a ⅛-in. mesh. The shotcrete was placed by lining machines to which trowels were attached and it was thought that the troweling would produce a smoother surface if the coarser aggregates were taken out. Later it was found that the material passing the ¼-in. screen was satisfactory and that the finish could be made equally smooth.

This experience indicates that cracking is not a function of the method of placement but rather of the composition of the aggregates.

Except on rare occasions the statement "The natural shotcrete surface is rough and covered with rebound" applies only to horizontal surfaces. Sometimes dust from the spray sticks to vertical surfaces but this usually does not include rebound. On horizontal surfaces a skillful nozzleman can eliminate most of the rebound or work it into the mix. The efficiency of the gun being used also has much to do with this. Uniformity of metering into the material hose effects a similar uniformity of hydration at the nozzle and hence the percentage of rebound and dust.

Application of shotcrete in "relatively thin layers" is necessary only for vertical or nearly vertical surfaces. On horizontal surfaces the shotcrete may be built to any reasonable thickness in one application. The skill of the operator has much to do with this. By "application" is meant one trip of the operator; all shooting is done in thin rapidly-repeated passes.

Immense amounts of good shotcrete having aggregates with fineness modulus less than 2.0 have been shot. Some of the best canal lining in the Rio Grande Valley of Texas* was made with a fine sand. After 24 years it seems as strong and durable as ever. In 1929, A. Tamm sent samples of most of the canal linings in the valley to the Pittsburgh Testing Laboratory for detailed examinations. Much to the surprise of everyone, the lining made with the local fine sand produced the highest strength and the lowest porosity.

To confine the uniformity of the fineness modulus to 0.20 either way may be too severe since shotcrete provides a kind of natural selection. It is thought that the coarser particles strike against other particles projecting from the cement matrix and thus are rejected as rebound. On vertical surfaces it may be that only the grains of sand which find a seat in the cement matrix adhere. If such is the case the engineer would not need to be too much concerned with the fineness modulus.

It is suggested that a recommendation be included prohibiting the lapping and tying together of mesh in such a way that two wires are together in parallel. Where this occurs there is sure to be a sand pocket and a water vein. Laps should be at ½ or 1½ the wire spacing both transversely and longitudinally.

Is it proper to specify that proportioning of the mix shall be "volumetrically batch measured"? Fine damp sand will bulk as much as 55 percent; coarse damp sand around 20 percent. By volume measurement the pro-

*Hidalgo County Water Control and Improvement District No. 7, Mission, Texas.

portions may vary as much as ⅓ depending on moisture content of the sand and its FM. Most of this difference would be eliminated by proportioning by weight. If the volumetric method is used it should be specified that corrections be made for bulking.

It is suggested that reference to final set be eliminated from the recommendations for time between coats of shotcrete. Provided the surface is clean, the bond to the preceding coat will be perfect no matter how long the time interval between coats.

With reference to screeding or rodding it might be more direct to say "to cut off high spots and expose low spots" instead of "trim off." No trimming should be done until the shotcrete has taken an initial set and then the surfaces should be cut with a sharp tool and not screeded in the ordinary sense. Dragging of the surface tends to open cracks which do not heal.

The recommendation that "Test cylinders should be made by shooting shotcrete into a mold made of hardware cloth (¾-in. metal mesh) to make cylinders 6 in. in diameter and 12 in. long" will not, as proved by tests by the writer, produce a true specimen of shotcrete. The shotcrete does not get the compaction that is obtained when the specimen is confined by adjacent bodies of the same material. When cylinders are cut from a slab larger than the required cylinder the values are exactly what they should be if the cutting is carefully done.

A generally used specification for cutting cylinders provides that:

> A 1 in. x 12 in. x 4 ft board or equivalent placed horizontally shall be shot with the mixture being used to a thickness of 4 in. or more. After the mortar has taken an initial set, usually in about one hour, the mortar shall be trimmed inward from the edges of the board approximately 1 in. to permit the placement of 4 in. screed boards. These boards shall then be set in place and used as guides for cutting the surface of the mortar by means of sharp-edged tools, to a plane which will be parallel to and 4 in. from the bottom of the slab. A 4 in. diameter by 6 in. height, wooden or steel cylinder, shall then be used to mark out specimens approximately 8 in. center to center and along the center line of the top surface of the slab. The material shall then be cut away, outside of the circular markings, by means of sharp edged tools such as a trowel, until specimens slightly more than 4 in. in diameter are obtained. The steel cylinder is then set on top of the specimen and is used as a vertical guide for a cutting spade having a sharp lower edge, a width equal to ⅓ the circumference of the cylinder, and a curved shape to fit the surface of the cylinder. This tool shall have a length approximating 8 in. and shall be equipped with suitable handle. It is operated vertically to shave the specimen to true dimensions using the cylinder as a guide. After being completed specimens shall immediately be covered with burlap and kept moistened for 24 hours after which they can be moved and immersed in water or otherwise cured.

Companion tests have shown that the values obtained from cylinders of this size are in accord with those of standard 6 x 12-in. cylinders. Laboratories testing the cylinders will penalize them 15 percent on account of the l/d standards set for concrete cylinders but such corrections are in error as proved by E. P. Stewart.* Apparently mixes without large aggregate do not react as do concrete mixes.

*Engineering News-Record, Nov. 9, 1933, p. 558.

By R. M. DOULL*†

One of the great advantages of pneumatic mortar is that when properly applied it forms a positive bond to the surfaces against which it is shot. The writer has conducted numerous investigations regarding this physical characteristic and believes that pneumatic mortar produces a better bond than that obtainable with other cementitious materials or methods. This feature is probably its most important characteristic and is not mentioned in the standard.

Pneumatic mortar is recognized as a material with high resistance to frost action, as many thousands of feet in the Canadian climate demonstrate. The most destructive frost condition is brought about by the freezing of water in the pores of the material being attacked. Since this condition is common in concrete structures and uncommon in pneumatic mortar the latter is apparently more dense and less porous.

A similar condition occurs in maritime areas. Concrete in tidal waters frequently spalls between high and low water levels. This is caused not only by frost action but by the formation of salt crystals in the pores of the concrete. The use of pneumatic mortar to repair such damages is an effective safeguard to the structure and there are thousands of square feet or such work standing up after 15 or 20 years service.

COMMITTEE CLOSURE

Before replying in detail to the discussions of Messrs. Crom and Doull, the committee wishes to thank both for their interest and critical study. It is also desired before replying to restate the objective of the committee in preparing the recommended practice. That objective was to prepare a standard describing the best current practice in specifying, directing and inspecting shotcrete work, for the guidance of engineers who might not have had extensive experience with this material. Believing that the usefulness of the recommended practice will depend largely upon its general application, it prescribes techniques which will best assure sound shotcrete for all uses and weather conditions without adding unduly to the cost of the less critical work.

The statement in the recommended practice that "The method of placement requires a lower water-cement ratio than is normally usable with ordinary concrete placement methods" is based on the comparison of a water content of between 4 and 5.5 gallons of water per sack of cement for fresh shotcrete in place, and a water content of between 5 and 8.5 gallons of water per sack of cement for fresh concrete. The data on water-cement ratio for sound shotcrete were obtained from a representative coverage of applicators, trade research groups, equipment manufacturers and large users. Generally where higher ratios were used, undesirable drying shrinkage was evident.

*General Manager, Canada Gunite Co., Ltd., Montreal, P. Q., Canada.

†Much of this discussion, covering the same ground as the previous discusser, has been omitted in the interest of brevity.

The water-cement ratio for sound concrete was obtained from the 1940 *Joint Committee Report*, "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete," Chapter 3, Tables 1, 2 and 3.

Referring to the water-cement ratios quoted by Mr. Crom from U. S. Dept. of Interior's *Concrete Manual*, it will be noted in the same paragraph of that manual that 3 percent diatomaceous earth was added to the shotcrete mix. This increased the water requirement beyond normal.

The best practice with regard to rebound is believed to be to do all those things which prevent its incorporation in the work. Otherwise it is believed that a nonuniform material will result.

The statement that "Shotcrete is well adapted for use in the construction of coatings over brick, concrete, steel and masonry; but under adverse weather conditions on deteriorated concrete surfaces and on many hydraulic structures the durability will probably be materially less than when used on unexposed surfaces and on nonhydraulic structures," is to advise the user of the "recommended practice" that shotcrete has definite limitations when used for such purposes. Usual experience has been that shotcrete is sufficiently porous so that coatings of it on structures exposed to weather or water will allow enough moisture to filter through to the contact between the shotcrete and the original material to permit freezing there, which in turn causes the coating to break its bond although the coating itself may remain intact for years after it has been loosened. Also, where coatings are applied to older concrete in hydraulic structures the surface of the latter may be deteriorated so that whatever bond is obtained between the coating and the base may be loosened by solution; again leaving the sound shotcrete in place. As in normal concrete which may be kept dry, the life and durability of dry shotcrete is materially superior to that which is subjected to wetting and drying or which is wet during freezing weather, as in hydraulic structures.

The statement that "The density of shotcrete is lower than the density of good concrete" is based on the measured weight of samples of each material. With ordinary siliceous aggregates, the density of concrete and shotcrete is approximately 150 and 142 lb per cu ft, respectively. These figures indicate the larger amount of air voids in shotcrete. In this fact, however, is believed to lie one of the principal virtues of shotcrete. These voids, which are not interconnected, appear to give freezing water an opportunity to expand without rupturing the surrounding material.

The statement "Shotcrete is more subject to shrinkage cracks than concrete" is based on numerous tests for drying shrinkage on the two materials. For example, some carefully obtained data available to the committee shows a range of 0.07 to 0.12 percent long-time drying shrinkage for shotcrete of various aggregate gradings and amounts of mixing water; while McMillan's *Basic Principles of Concrete Making* and the USBR 1949 *Concrete Manual* show a range for concrete of from 0.04 to 0.05 percent.

The data quoted from Staley and Peabody's paper,* purporting to show that concrete shrinks more than gunite are at considerable variance with the conclusions of other researchers.

The statement that "The natural shotcrete surface is rough and covered with rebound" is based on the observations by committee members of a large and representative number of shotcrete applications. Vertical surfaces in general are less rough than horizontal and sloped surfaces, but even so they have a surface similar to stucco.

The recommendation that "The time interval between successive applications in sloping, vertical or overhanging work must be sufficient to allow initial, but not final, set to develop" is for the purpose of obtaining a surer bond between applications than would be obtained otherwise. The bond obtained by allowing final set to develop and then, after cleaning the surface with water, applying the subsequent application, may be inferior.

The specification of a fineness modulus of not less than 2.50 nor more than 3.30, and the requirement that "Any shipment of fine aggregate made during the progress of the work which varies more than 0.20 either way from the fineness modulus of the preliminary sample should be rejected, unless, by changes in proportions, it may be readily made to comply with the requirements of this section," are in accordance with the requirements of 1940 *Joint Committee Report*, "Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete." It is considered both prudent and practical to use the same requirements for shotcrete aggregates as those in common use for concrete fine aggregates.

In special cases, such as those where only very fine aggregate is available except at excessive transportation costs, careful study may show a saving by indicating a special mix or a change in ordinary application procedure by which sound shotcrete may be obtained; even though otherwise unsatisfactory materials are used or unfavorable application conditions exist. The committee is not unmindful of the instances where it may be more economical to deviate from a conservative general practice; but it suggests that before such deviations are accepted, a careful investigation be carried out to assure that sound shotcrete will result if the deviations are followed. It appears to the committee that the instances given in the discussions where sound shotcrete was obtained using very fine sand and large water contents comes under the special problem cases mentioned above.

Offsetting the laps of reinforcing mesh or steel to avoid sand pockets is common practice and is desirable as pointed out by Mr. Crom.

Volumetric batching is satisfactory for shotcrete because bulking of the sand is reasonably constant as a result of the practical limit of 3 to 5 percent moisture in the sand. If dryer or wetter sand is used the shotcrete equipment will not operate satisfactorily. Weigh batching is equally acceptable.

*Staley, Howard R. and Peabody, Dean, Jr., "Shrinkage and Plastic Flow of Prestressed Concrete," ACI JOURNAL, Jan. 1946, *Proc.* V. 42, pp. 229-244.

The statement that "Because of the necessity of disposing of rebound clear of the work, shotcrete is applied in relatively thin layers, successive applications being necessary for heavy sections," is based on the committee's belief that rebound should be removed and not incorporated in the work. The incorporation of rebound, while saving money, is detrimental to the quality of the shotcrete work.

The statement that "Test cylinders should be made by shooting shotcrete into a mold of hardware cloth (¾ in. metal mesh) to make cylinders 6 in. in diameter and 12 in. long" is based on the belief that it would be difficult to justify on all but a small portion of shotcrete jobs the greater cost of cutting test cylinders from prepared slabs. Where the usage is sufficiently critical that the purchaser is justified in paying the added costs, the use of the more exact method could be written into the construction specifications.

ACI Standard

Specifications for Concrete Pavements and Bases (ACI 617-51)*

Reported by ACI Committee 617

H. F. CLEMMER
Chairman

T. J. KAUER
A. T. GOLDBECK
FRED HUBBARD
M. ALLAN WILSON
FRANK H. JACKSON
BAILEY TREMPER
STANTON WALKER
W. E. HAWKINS

SYNOPSIS

Standard specifications for the construction of portland cement concrete pavement and base under normal conditions, including preparation of the subgrade.

Subjects covered include: materials; proportions of materials based on design for minimum strength or based on uniform cement factor; measurement and handling of materials; mixing; high-early strength concrete; subgrade preparation; forms; installation of joints and reinforcement; placing and finishing concrete; and curing.

SCOPE

1. Concrete pavement and base

These specifications apply to the construction of portland cement concrete pavement and base under normal conditions, including the preparation of the subgrade, and shall govern unless modified by special provisions to take into account unusual conditions of traffic, subgrade, drainage, exposure and other factors.

MATERIALS

2. Approval of sources of material supply

Portland cement, aggregates and water shall be furnished only from sources of supply approved by the engineer before shipments are started. The basis of approval of such sources shall be the ability to produce materials of the quality and in the quantity required.

3. Portland cement

(*a*) Cement shall conform to the requirements of the current American Society for Testing Materials Standard Specifications for Portland Cement

*Adopted as a standard of the American Concrete Institute at its 47th annual convention, Feb. 20, 1951 as reported by Committee 617; ratified by letter ballot Apr. 5, 1951. Title No. 47-49 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 22, No. 9, May 1951, *Proceedings* V. 47. Title No. 47-49 supersedes 41-27 published in June 1945 and 47-6 published in Oct. 1950. Separate prints in covers are available at 50 cents each. **Discussion** of this paper (copies in **triplicate**) should reach the Institute not later than Sept. 1, 1951. Address 18263 W. McNichols Rd., Detroit 19, Mich.

(Designation C 150) or for Air-Entraining Portland Cement (Designation C 175). The Engineer shall designate the type of cement which is required.

(*b*) Cement shall be protected from the weather and against loss in handling or in transit. Either package or bulk cement may be used.

4. Aggregates

(*a*) Aggregates shall conform to the requirements of the current A.S.T.M. Standard Specifications for Concrete Aggregates (Designation C 33) as amplified by the insertion of limitations in the blanks provided, to meet local conditions.

Coarse aggregate shall be furnished in two separate sizes with the separation at the ¾-in. sieve when combined material graded from No. 4 to 1½ in. is required and at the 1-in. sieve when combined material graded from No. 4 to 2 in. is required.

(*b*) Aggregates shall be so stored as to prevent the inclusion of foreign material. Aggregates shall not be placed upon the finished subgrade. Aggregates of different kinds and sizes shall be placed in different stock piles. Stock piles of coarse aggregates shall be built up in successive horizontal layers not more than 3 ft thick. Each layer shall be completed before the next is started. Should segregation occur, the aggregates shall be remixed to conform to the grading requirements.

(*c*) Frozen aggregates or aggregates containing frozen lumps shall be thawed before use. Washed aggregates and aggregates produced or manipulated by hydraulic methods shall be allowed to drain for at least twelve hours before use. Stock piles or cars and barges equipped with weep holes are considered to offer suitable opportunity for drainage.

5. Water

Water used in mixing or curing concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable or other substances harmful to the finished product. Sources of water shall be maintained at such a depth, and the water shall be withdrawn in such a manner (by enclosing pump intake, etc.), as to exclude silt, mud, grass or other foreign materials.

6. Reinforcement steel and accessories

(*a*) *Steel wire fabric*—Steel wire fabric reinforcement shall conform to the requirements of the current A.S.T.M. Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (Designation A 185).

(*b*) *Bar mats*—The steel in bar mats shall conform to the requirement of the current A.S.T.M. Standard Specifications for Bar or Rod Mats for Concrete Reinforcement (Designation A 184). Members shall be of the size and spacing shown on the plans. All intersections of longitudinal and transverse bars shall be securely wired, clipped or welded together.

(*c*) *Dimensions of wire fabric and bar mats*—The width of fabric sheets or bar mats shall be such that, when properly placed in the work, the extreme longitudinal members of the sheet or mat will be located not less than 3 in.

nor more than 6 in. from the edges of the slab. The length of fabric sheets or bar mats shall be such that, when properly placed in the work, the reinforcement will clear all transverse joints by not less than 2 in. nor more than 4 in. as measured from the center of the joint to the tip ends of the longitudinal members of the sheet or mat.

(*d*) *Bars*—Reinforcement bars shall conform to the requirements of the current A.S.T.M. Standard Specifications for Billet-Steel Bars for Concrete Reinforcement (Designation A 15) or for Rail-Steel Bars for Concrete Reinforcement (Designation A 16). Bars depending upon bond for their effectiveness shall conform to the requirements of the current A.S.T.M. Standard Specifications for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement (Designation A 305) and shall be free from excessive rust, scale, or other substances which prevent the bonding of the concrete to the reinforcement.

(*e*) *Tie bars*—Tie bars shall be deformed steel bars conforming to the requirements of the specifications for reinforcement bars except that rail steel bars shall not be used where they are to be bent and restraightened.

(*f*) *Dowels and sleeves*—Dowels shall be plain round bars conforming to the requirements of the specifications for reinforcement bars. Dowel bars shall not be burred, roughened or deformed out of round in such a manner as to affect slippage in the concrete.

When metal sleeves are used, they shall cover the ends of the dowels for not less than 2 in. nor more than 3 in. The sleeve shall be closed at one end. It shall have a suitable stop to hold the end of the bar at least 1 in. from the closed end of the sleeve. It shall be of such rigid design that the closed end will not collapse during construction.

(*g*) *Chairs*—Chairs for holding tie rods in correct position while the concrete is being placed shall be of metal, slightly rounded and tapered at one end. The minimum dimensions shall be: Thickness 16 gage (U. S. Standard Gage, 1893), length 12 in., width $1\frac{3}{4}$ in. measured along the metal.

(*h*) *Stakes*—Stakes used to support expansion joint fillers shall be channel- or U-shaped, at least $\frac{3}{4}$ in. wide and $\frac{3}{8}$ in. deep and of metal not thinner than 16 gage (U. S. Standard Gage, 1893). They shall be 15 in. long or longer if required to provide proper bearing support.

7. Subgrade paper

Paper to be placed on the soil base shall conform to the requirements of the current American Association of State Highway Officials Standard Specification for Subgrade Paper, M 74.

8. Expansion joint filler

Expansion joint filler shall conform to the requirements of the current A.S.T.M. Specifications for Preformed Expansion Joint Fillers for Concrete D 544.

9. Metal joint plate and pins

Plates for tongue and groove joints shall be steel or iron not thinner than 16 gage, (U. S. Standard Gage, 1893). Each section shall be a continuous

strip of metal not more than 15 ft long having a width ½ in. less than the depth of the pavement; it shall be provided with an end connection which will hold the ends of strips firmly together. Each section shall be of the specified cross section, and shall be punched for dowels or tie bars, and pins, as shown on the plans.

Pins shall be channel shaped, pressed out of sheet steel of not less than 12 gage (U. S. Standard Gage, 1893) and not less than 15 in. long.

10. Cover materials for curing

(*a*) *Burlap*—Burlap shall be made from jute or hemp and, at the time of using shall be in good condition, free from holes, dirt, clay, or any other substance which interferes with its absorptive quality. It shall not contain any substance which would have a deleterious effect on the concrete. Burlap shall be of such quality that it will absorb water readily when dipped or sprayed and shall weigh not less than 7 oz per sq yd when clean and dry. Burlap made into mats may be used if care in handling is exercised to avoid marring the finished surface of the concrete.

(*b*) *Cotton mats*—Cotton mats for curing concrete shall conform to the requirements of the current AASHO Standard Specifications for Cotton Mats for Curing Concrete Pavements. (Designation M 73).

TESTS OF MATERIALS

Materials shall be tested in accordance with methods referred to in the appropriate specifications, except as otherwise specified.

11. Flexural strength tests of concrete as basis of design

Specimens for flexural strength tests to be used as the basis for the design of concrete mixtures shall be molded and cured in accordance with the current A.S.T.M. Standard Method of Making and Curing Concrete Compression and Flexure Test Specimens in the Laboratory (Designation C 192). Specimens shall be tested in accordance with the current A.S.T.M. Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading), (Designation C 78).

12. Flexural strength tests of concrete for field control

(*a*) Flexural tests of concrete specimens molded and cured in the field shall be made, whenever feasible, using the testing machine described in A.S.T.M. Method C 78. Results of tests of field cured specimens should not be used as a basis for design of mixtures. If another type of testing machine is used, results obtained with it should be correlated with those obtained from the standard apparatus. Apparatus for making flexure tests of concrete shall be so designed as to incorporate the following principles:

(1) The distance between supports and points of load application shall remain constant for a given apparatus.

(2) The load shall be applied normal to the loaded surface of the beam and in such a manner as to avoid eccentricity of loading.

(3) The direction of the reactions shall, at all times during a test, be parallel to the direction of the applied load.

(4) The load shall be applied at a uniform rate and in such a manner as to avoid shock.

(5) The ratio of distance between point of load application and nearest reaction to the depth of the beam shall not be less than one.

Note: The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

(*b*) *Molding, curing and marking*—Concrete for the field test specimens shall be secured in accordance with the current A.S.T.M. Method of Sampling Concrete (Designation C 172) from the concrete deposited on the subgrade. The specimens shall be molded, finished and cured as described in the current A.S.T.M. Method of Making and Curing Concrete Compression and Flexure Tests in the Field (Designation C 31). Specimens shall be tested in accordance with the current A.S.T.M. Standard Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third-Point Loading), (Designation C 78). They shall be cured, as nearly as practicable, in the same manner as the pavement concrete. They shall be properly identified as to date of molding and location of pavement represented; weather conditions prevailing at the time of molding shall be noted.

(*c*) *Number of specimens*—At least two beams shall be made for each 1000 sq yd of pavement.

13. Specific gravity and absorption of aggregates

(*a*) *Fine aggregate*—The bulk specific gravity and absorption of fine aggregate shall be determined in accordance with the current A.S.T.M. Standard Method of Test for Specific Gravity and Absorption of Fine Aggregates. (Designation C 128).

(*b*) *Coarse aggregate*—The bulk specific gravity and absorption of coarse aggregate shall be determined in accordance with the current A.S.T.M. Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate (Designation C 127).

14. Consistency

Consistency shall be determined in accordance with the current A.S.T.M. Standard Method of Slump Test for Consistency of Portland Cement Concrete (Designation C 143).

15. Air content

The air content of plastic concrete shall be determined in accordance with current A.S.T.M. Standard Methods of Test for Air Content: (1) Gravimetric (Designation C 138), (2) Volumetric (Designation C 173) or (3) Pressure Method (Designation C 231).

PROPORTIONS OF MATERIALS

16. Basis of Proportions

The proportions of water, cement and aggregates shall be in accordance with *Proportions based on design for minimum strength* (Section 18) or in accordance with *Proportions based on uniform cement factor* (Section 19) as specified in the special provisions.

17. Air content

When concrete is made with an air-entraining cement or air-entraining admixture, the percentage of air shall be maintained between 3-6 percent as determined by methods stated under Section 15 of these specifications.

18. Proportions based on design for minimum strength

(*a*) The proportions of cement, fine aggregate, coarse aggregate and water to be used in the mix shall be determined by the Engineer, within the limits of Sections 18(*b*) and 18(*c*), by means of laboratory tests of the flexural strength of concrete made with aggregates from the same sources and of the same gradings as will be employed in the work and that portland cement which is found to produce the lowest strength concrete of any acceptable cement available for the work.

(*b*) The mixture determined upon shall produce workable concrete having a slump of 2 in. to 3 in. for unvibrated concrete, or ½ in. to 1½ in. for vibrated concrete, and a modulus of rupture at 14 days of not less than 550 psi as determined from specimens made, cured and tested in accordance with the current A.S.T.M. Method C 78.

(*c*) The resulting proportions shall be such that the mixing water, including free surface moisture on the aggregates but exclusive of moisture absorbed by the aggregates, shall not exceed 6 gal. per sack of cement for any individual batch in localities where the concrete will be subjected to severe freezing and thawing conditions. In no case shall the mixing water exceed 6½ gal. per sack of cement for any individual batch. The cement content shall be not less than 5 sacks per cu yd.

(*d*) Unless otherwise specified in the special provisions the following requirements shall govern the contractural relations concerning proportions based on design for minimum strength:

(1) Upon request, the Engineer will furnish prospective bidders with information as to the proportions by weight required for aggregates from established sources available for use on the project. This information will also include the grading of the aggregates used in determining these proportions.

(2) Promptly after receipt of notice of award of the contract, the Contractor shall furnish the Engineer with the location, or locations of the source or sources of aggregates which he proposes to use. The proportions will be designated by the Engineer. Except as hereinafter provided the designated proportions shall govern as long as materials are furnished from the sources designated and as long as they continue to meet the requirements specified.

(3) If, during the progress of the work, the Contractor proposes to use aggregates from approved sources other than those originally designed, the Engineer will designate the new proportions to be used.

(4) If satisfactory plasticity and workability are not secured using the proportions and aggregates originally designated, the Engineer may alter such proportions. If such alterations change the designated cement factor originally fixed by 2 percent or less, no adjustment in the amount paid the Contractor shall be made. If such alterations change the designated cement factor by more than 2 percent, the source and quality of the aggregates remaining the same, payment shall be adjusted for or against the Contractor in whatever amount the total cost of materials, f.o.b. Contractor's material yard, has been increased or decreased by more than 2 percent. The calculation of the amount of such increase or decrease shall be based upon the designated cement factor and not on count of bags of cement used or of the batches where bulk cement is used.

TABLE 1—PROPORTIONS BASED ON A FIXED CEMENT CONTENT AND SPECIFIED SLUMP*

Specification requirements					Quantities of materials to be used for proportioning trial batches			
						Pounds of aggregates per 94-lb bag of cement††		
Type of concrete**	Method of placing	Type of coarse aggregate†	Range in slump, in.	Cement, bags per cu yd‡	Water, gal. per bag	Fine aggregate§	Coarse aggregates	
							Small	Large
Plain	Machine	Gravel	2-3	6.0	5.0	175	140	215
Plain	Machine	Crushed stone	2-3	6.0	5.6	200	130	200
Plain	Machine	Slag	2-3	6.0	5.9	210	110	160
Plain	Vibrated	Gravel	1-1½	5.5	5.0	175	170	255
Plain	Vibrated	Crushed stone	1-1½	5.5	5.6	200	160	240
Plain	Vibrated	Slag	1-1½	5.5	5.9	210	130	200
Air-ent.	Machine	Gravel	2-3	6.0	4.5	155	140	215
Air-ent.	Machine	Crushed stone	2-3	6.0	5.1	180	130	200
Air-ent.	Machine	Slag	2-3	6.0	5.3	190	110	160
Air-ent.	Vibrated	Gravel	1-1½	5.5	4.5	155	170	255
Air-ent.	Vibrated	Crushed stone	1-1½	5.5	5.1	180	160	240
Air-ent.	Vibrated	Slag	1-1½	5.5	5.1	190	130	200

*Aggregate weights are based on assumed bulk specific gravity of 2.65 for sand, gravel and crushed stone and 2.25 for slag, all in saturated, surface dry condition. For aggregates having other specific gravities, the desired weights equal tabulated weights of respective materials, divided by the assumed specific gravities multiplied by the actual specific gravities of the materials to be used.

†Coarse aggregates are 1½ in.-No. 4 or 2 in.-No. 4 and graded approximately 40 percent small and 60 percent large separated on the ¾ in. or 1 in. sieve, respectively.

‡Compliance with this requirement shall be determined by means of a yield test made in accordance with A.S.T.M. Standard Method C 138. If the cement content calculated from this test varies from the designated cement content by more than 2 percent, the total weight of aggregate per bag of cement shall be adjusted as necessary to bring the cement content within the specified limits.

§Fine aggregate proportions are based on the use of well graded natural sand of 2.75 fineness modulus.

**Air content is assumed as 1 percent for plain mixes and 4 percent for air-entraining mixes.

††If the aggregates contain more water than required for saturation, the aggregate weights should be increased by the weight of surface water present; if they contain less water than required for saturation, the weights should be decreased by the amount in weight of water necessary to attain saturation of aggregate. Free water on aggregates should be accounted as a part of the mixing water.

19. Proportions based on fixed cement content

When concrete having a fixed cement content is specified, the quantities shall be those given in Table 1 properly adjusted to compensate for differences in specific gravities. Upon approval by the Engineer, these compensated quantities of materials shall be further adjusted by the Engineer at any time to attain the desired degree of workability, the specified slump, and the specified cement content. Batch weights thus determined, shall be corrected to take into account the moisture condition of the aggregates as used.

MEASUREMENT AND HANDLING OF MATERIALS

20. Cement, aggregates, water

(*a*) Standard size sacks of cement as packed by the manufacturer shall be considered to weigh 94 lb net. Bulk cement and cement from fractional sacks shall be weighed.

(*b*) When package cement is used, the cement shall be emptied from the sacks into the batch immediately prior to mixing. When bulk cement is used, satisfactory methods of handling and weighing shall be employed. A separate hopper shall always be so designed and operated that the quantity of cement for each batch will be maintained in a separate container so as not to come in direct contact with the aggregates.

(*c*) Aggregates shall be weighed. Each size of aggregate shall be weighed separately.

(*d*) The scales for weighing cement and aggregates shall be accurate within ½ of 1 percent throughout the range of use. Operation shall be within a maximum allowable error of 1 percent for cement and 2 percent for aggregates.

(*e*) Mixing water may be measured by weight or by volume. The water-measuring device shall be accurate to ½ of 1 percent. Operation shall be required to be within a maximum allowable error of 1 percent. When wash water is used as a portion of the mixing water for succeeding batches, it shall be measured according to this requirement.

MIXING

21. Mixing at site or at central mixing plant

(*a*) The concrete shall be mixed in a batch mixer. When a drum mixer is used, it shall conform to the requirements of the concrete mixer standards of the Mixer Manufacturers Bureau of the Associated General Contractors of America. If another type of mixer is used, it shall be of a type satisfactory to the Engineer. The mixer shall be capable of combining the aggregates, cement and water into a thoroughly mixed and uniform mass within the specified time, and of discharging the mixture without segregation. Each batch of concrete shall be mixed for one minute or more after all materials, exclusive of the mixing water, are in the mixer drum. The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and will continue to flow for a period which may extend to the end of the first one-third of the specified mixing time. The mixer shall rotate at the rate recommended by its manufacturer. Concrete shall be mixed only in quantities required for current use; any concrete which has set so that it cannot be placed properly shall not be used. Retempering of concrete which has partially set, by mixing with additional water, will not be permitted.

(*b*) The mixer shall be equipped with a suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked. Controls shall be so arranged that the water can be started only while the mixer is being charged and so as to lock automatically the discharge lever until the batch has been mixed the required time after all materials are in the mixer. The entire contents of the drum shall be discharged after each charge has been mixed the required time. In case of mixing at the site suitable equipment for discharging and spreading the concrete on the subgrade shall be provided. The mixer shall be cleaned at suitable intervals. The pick-up and throw-over blades in the drum shall be replaced when they have lost 10 percent of their depth. The volume of the mixed material per batch shall not exceed the manufacturer's normal rated capacity of the mixer, exclusive of the overload. The manufacturer shall install a plate upon the mixer stating the rated capacity and the recommended revolutions per minute.

22. Ready-mixed concrete

Ready-mixed concrete shall be mixed and transported in accordance with the current A.S.T.M. Specifications for Ready-Mixed Concrete (Designation C 94).

HIGH-EARLY STRENGTH CONCRETE

23. Methods of production

High-early strength concrete shall be produced by one of the following methods, or any combination thereof, as specified in the special provisions.

(*a*) By the use of high-early strength portland cement Type III in lieu of normal portland cement (Type I or IA or Type II or IIA).

(*b*) By the use of additional portland cement (Type I or IA or Type II or IIA) in which case the total amount of cement shall not exceed 7 bags of cement per cu yd of concrete.

(*c*) By the use of calcium chloride as one of the ingredients of the concrete in an amount between 1 and 2 lb of calcium chloride per sack of cement. Calcium chloride may be added either dry or in solution. When used in solution, it is convenient so to proportion the solution that 1 quart contains 1 lb of calcium chloride.

High-early strength concrete shall meet the requirements of these specifications for portland cement concrete.

The relative value of the above methods for producing early strength is usually in the order stated, beginning with the highest.

SOIL FOUNDATION PREPARATION

24. Grading stakes

Grading stakes shall be protected by the Contractor. Stakes which become disturbed shall be reset at the Contractor's expense.

25. Definitions

The following definitions shall apply in these specifications where applicable:

Embankment foundation—The material on which an embankment is placed.

Embankment (fill)—A raised structure of soil-aggregate or rock.

Subgrade material (Basement soil)—The material in excavations (cuts), and embankments (fills), and embankment foundations immediately below the first layer of subbase, base or pavement and to such depth as may affect the structural design.

Soil subbase—Specified or selected material of planned thickness placed as foundation for a base.

Soil base—Specified or selected material of planned thickness placed as a foundation for a pavement.

Silt-clay (Minus No. 200 material)—Fine soil particles which will pass the No. 200 sieve.

(*a*) *Silt fraction*—Material passing the No. 200 sieve and larger than 0.005 mm.

(*b*) *Clay fraction*—Material smaller than 0.005 mm including colloids which are the particles of the clay fraction smaller than 0.001 mm.

26. Clearing right-of-way

Where fills are less than 10 ft high, all sod, underbrush, trees, tree stumps and saplings shall be grubbed and entirely removed; when fills more than 10 ft high are to be made, the ground shall be cleared of all underbrush, and all trees and saplings shall be cut off not over one foot above the ground.

27. Solid rock

Solid rock (boulder of 1 cu yd or more in content, or ledges in their original bed) shall be removed 6 in. below grade and shall be paid for at the contract price per cu yd of solid rock.

28. Excavated materials

Material excavated in cuts may be used in fills on the job provided the material conforms to the specifications for fill materials contained herein. Excess or unsuitable material shall be disposed of by the Contractor at his expense.

Any excavation of approved soil below the surface of the base as shown on the plans shall be refilled with approved material compacted as provided herein for filling and compaction at the Contractor's expense.

29. Removal of unsuitable material

All unsuitable material shall be removed to a depth of at least 18 in. below the finished surface of the soil base. The contractor will be paid for the work at the prices bid for grading and materials used.

When unsuitable material is removed from the soil base, the surface shall be brought to the correct elevation with approved material placed and compacted as specified herein. Payment for this work will be made at the contract prices for grading and materials.

30. Borrowed material

Borrowed material shall be secured from pits indicated on the plans. If no such location is indicated or the quantity of the material at the pits is insufficient, the Contractor shall furnish material conforming to the requirements of these specifications. Payment shall be made for such material at the price bid for borrow per cu yd.

31. Soil base material

Soil base material shall meet the requirements as specified in the current AASHO Specification for Materials for Stabilized Base Course, M 147.

32. Soil fill material

All material used in earth fills must meet the following specifications and may be rejected on visual inspection pending the testing of samples.

Fill material shall be a well-graded combination of granular material, silt and clay soil. The material shall have a minimum of 80 percent passing the No. 4 sieve, at least 65 percent retained on, and at least 20 percent passing the No. 200 sieve. No gravel or stone shall be larger than one-third the depth of the layer to be placed. The soil shall have a liquid limit, as determined by the current AASHO Method of Determining the Liquid Limit of Soils, T 89, not greater than 35. The material to be used shall be free from trash, brick, broken concrete, tree roots, sod, ashes or cinders.

Samples of the fill material will be taken from every 500 cu yd or fraction thereof. Samples will also be taken whenever in the opinion of the Engineer the texture of the material appears to be changing.

Contractors desiring approval of the source of a material shall submit samples at least one week in advance of the desired date of approval. Acceptance of material from any location shall not be construed as approval of the entire location, but only insofar as it continues to meet the specifications.

33. Compaction equipment

Compaction may be accomplished by means of smooth rollers, pneumatic tired rollers, tamping or sheepsfoot rollers. However, the equipment selected shall be capable of compacting the soils to density requirements hereinafter specified.

When compaction is to be accomplished in places inaccessible to rolling, mechanical tampers capable of striking a blow equivalent to at least 250 lb per sq ft shall be used.

34. Consolidation of road foundation

All fills, soil bases, and soil subbases shall be compacted in layers not greater than 6 in. in depth. Each layer shall be compacted to at least an average minimum density requirement expressed as a percentage of the maximum density as determined by the current AASHO Standard Laboratory Method of Test for the Compaction and Density of Soil, T-99. The field density shall not be less than the percentage of the maximum density shown in the following table:

Standard of compaction or maximum density obtained by Method T-99, lb per cu ft	Minimum compaction, required percent of maximum density
90 to 99.9	100
100 to 119.9	95
120 and above	90

35. Payment for grading

The contract prices for grading shall include the cost of excavating and filling, clearing and grubbing, excavating and removing unsuitable materials as required, shaping the subgrade to the prescribed lines and grades, sloping cuts, intersections and approaches, and rolling or tamping below the subgrade in the case of fills; and in connection with street construction, sloping and filling between the curb and sidewalk pavement, and grading and shaping of sidewalk spaces where shown on the plans. Payment shall be made at price bid per cu yd computed to the grades and slopes shown on the plans.

36. Wetting the soil base

Except where subgrade paper is required by the special provisions the soil base shall be thoroughly wetted a sufficient time in advance of the placing of the concrete to insure that there will be no puddles or pockets of mud when the concrete is placed. The degree of saturation shall depend upon the characteristics of materials in the base.

37. Testing and correcting the soil base

Immediately prior to placing concrete, the soil base shall be tested for conformity with the cross section shown on the plans by means of an approved template riding on the side forms. If necessary, material shall be removed or added, as required, to bring all portions of the soil base to the correct elevation. It shall then be thoroughly compacted and again tested with the template. Concrete shall not be placed on any portion of the soil base which has not been tested for correct elevation.

If the soil base is disturbed after acceptance, it shall be reshaped and compacted without additional compensation. Payment for compacting soil base shall be included in the contract prices for grading.

38. Placing subgrade paper

When specified in the special provisions the soil base, after it has been shaped and compacted, shall be covered with subgrade paper. Adjacent strips of paper shall lap 4 in. and ends shall lap 12 in. After being placed on the base, the paper shall be kept reasonably intact and shall not be hauled over nor have unnecessary holes punched through it.

FORMS

39. Material and dimensions

Side forms shall be made of metal having a thickness of not less than $\frac{7}{32}$ in. and shall have a depth equal to the specified edge thickness of the concrete. Building up of forms shall not be permitted. Flexible or curved forms of proper radius shall be used for curves of 100 ft radius or less. Forms shall not deflect more than $\frac{1}{4}$ in. when tested as a simple beam with a span of 10 ft and a load equal to that which the finishing machine or other construction equipment will exert upon them. Forms 8 in. or more in height shall be at least 8 in. wide at the base; forms less then 8 in. in height shall have a base width at least equal to the height of the forms. The flange braces must extend outward on the base not less than $\frac{2}{3}$ the height of the form. The forms shall be free from warp, bends, or kinks. The top of the form shall not vary from a 10 ft straightedge by more than $\frac{1}{8}$ in. at any point and the side of the form by more than $\frac{1}{4}$ in.

40. Base support

The subgrade under the forms shall be compacted and cut to grade so that the forms, when set, shall be uniformly supported for their entire length and at the specified elevations. Subgrade found to be below established grade at the form line shall be filled to grade in lifts of $\frac{1}{2}$ in. or less for 18 in. on each side of the base of the form and thoroughly re-rolled or tamped. Imperfections and variations above grade shall be corrected by tamping or by cutting, as necessary.

41. Grade alignment

The alignment and grade elevations of the forms shall be checked and the necessary corrections made by the Contractor immediately before placing the concrete. When any form has been disturbed or any subgrade thereunder has become unstable, the form shall be reset and rechecked.

42. Staking forms

Forms shall be staked with three or more pins for each 10 ft section. A pin shall be placed adjacent to each side of every joint if required. Form sections shall be tightly joined by a locked joint free from play or movement in any direction. Forms shall be cleaned and oiled prior to the placing of concrete.

43. Advance setting

Forms shall be set for at least 300 ft in advance of the point where concrete is being placed.

44. Removal of forms

Forms shall remain in place at least 12 hours after placing the concrete. If the air temperature is below 50 F at any time during the 12-hour period from the time the concrete is placed, the forms shall not be removed until 36 hours after placing of the concrete, unless high-early strength concrete is being used.

INSTALLATION OF JOINTS AND REINFORCEMENT

45. Joints

(*a*) All longitudinal and transverse joints shall conform to the details and positions shown on the plans.

(*b*) All joints shall be constructed true to line with their faces perpendicular to the surface of the pavement. Joints shall not vary more than ¼ in. from a true line or from their designated position.

(*c*) The surface of the pavement adjacent to all joints shall be finished to a true plane and edged to a radius of ¼ in. or as otherwise shown on the plans. The surface across the joints shall be tested with a 10-ft straightedge as the joints are finished and any irregularities in excess of ⅛ in. shall be corrected before the concrete has hardened.

(*d*) Keyways, when required, shall be accurately formed with templates of metal or wood. The gage, or thickness, of the material in the template shall be such that the full keyway as specified is formed.

46. Longitudinal joints

Longitudinal joints shall be constructed along or parallel to the centerline of the pavement unless otherwise specified.

(*a*) *Metal keyway joints*—Longitudinal "metal strip" joints shall be formed by installing a metal parting strip of the gage, shape and dimensions shown on the plans, to be left permanently in place. The metal strip shall be held securely in place, true to line and grade by suitable steel pins, which may be either channel shaped or round bars, spaced at intervals that average not less than 3 ft and in no case more than 4 ft. The minimum length of metal strips shall be 10 ft and adjoining sections shall be securely fastened by lapping and pinning, by means of a slip joint, or other approved method. The Contractor shall furnish an approved gage to ride on the side forms for checking the position of the parting strip before concrete is placed against it.

(*b*) *Dummy joints*—Longitudinal "dummy groove" or weakened plane joints shall be formed by a groove or cleft in the top of the slab. The groove shall be ⅜ in. wide at the surface and ¼ in. wide at the bottom unless otherwise specified. It shall be made in the plastic concrete by a suitable tooling device and shall extend vertically downward from the surface to at least ⅓ and not more than ½ the depth of the concrete.

(*c*) *Construction joints*—Longitudinal construction joints (*i.e.*, joints between slabs placed separately) shall be formed by the use of standard steel side forms with keyway, unless otherwise indicated in the plans. Provision shall be made for the installation of tie bars as noted in these specifications, or in the plans or special provisions.

(*d*) *Tie bars*—Tie bars not less than ½ in. diameter and 42 in. long, unless otherwise specified, shall be placed across all longitudinal joints. Tie bars shall be placed at right angles to the centerline and shall be spaced at intervals of 30 in. unless otherwise shown on the plans. They should be held in a position approximately parallel to the transverse axis of the pavement and midway between the top and bottom surfaces of the slab. Tie bars may be bent at right angles against the form at longitudinal construction joints, unless threaded bolt or other assembled tie bars are specified.

47. Expansion joints at structures

Expansion joints shall be formed about all structures and features projecting through, into, or against the pavement. Unless otherwise indicated on the plans, such joints shall be not less than ¼ in. thick and shall be of the premolded type.

48. Transverse expansion joints

Transverse expansion joints shall be constructed at right angles to the centerline of the pavement, unless otherwise required, and shall extend the full width of the pavement.

(*a*) *Premolded expansion joints*—Transverse premolded expansion joints shall be formed by securely staking an approved "installing bar" or installing device perpendicular to the proposed surface of the pavement. The installing bar shall be of substantial metal plate and shall have a length ½ in. less than the required width of the slab and shall be cut to the required depth and crown of the slab. It shall be securely staked in position so that the top edge, unless otherwise provided on the plans, will be uniformly ¼ in. below the pavement surface. The lower edge shall be cut to conform to the prescribed cross section of the subgrade. The installing bar shall be slotted from the bottom as necessary to permit the installtion of the required dowels. Suitable means shall be provided on the bar for facilitating its removal. Header boards, sheet metal holders or other devices used in lieu of the installing bar shall be subject to approval by the Engineer. The joints shall be protected against damage until they are installed in the work. Joints damaged during transportation, or by careless handling, or while in storage shall be replaced or repaired by the Contractor. Repaired joints shall not be used until they have been approved by the Engineer.

(*b*) *Premolded joint filler*—The designated premolded joint filler shall be appropriately punched to the exact diameter and at the locations of the dowels. It shall be furnished in lengths equal to one-half the designated width of the slab. Where more than one section is used in a joint, they shall be securely placed or clipped together. The premolded joint filler shall

be placed on the side of the "installing bar" nearest the mixer. The bottom edge of the filler shall extend downward to or slightly below the bottom of the slab, and the top edge, unless otherwise prescribed, shall be held about ½ in. below the surface of the pavement in order to allow the finishing operations to proceed continuously. The top edge of the filler shall be protected while the concrete is being placed, by a metal channel cap of at least 10 gage material, having flanges not less than 1½ in. deep. The installing device may be designed with this cap self-contained.

49. Transverse contraction joints

(*a*) *Metal strip type*—Transverse "metal strip" contraction joints shall be formed during the placing of the concrete by installing a metal parting strip to be left in place. This strip shall conform to the requirements for type, gage, shape, and dimensions shown on the plans or indicated in the special provisions and shall be securely staked in place. This strip shall be temporarily capped with a metal channel cap. The dowel assembly and the method of placing it shall be as indicated for transverse expansion joints, except that sleeves or caps on dowels will not be required. Concrete shall be deposited as for transverse expansion joints. After the longitudinal floating has been completed but before the surface is finished, the metal cap shall be removed and the concrete edged, and the joint sealed as required for expansion joints.

(*b*) *Weakened plane type*—Transverse joints of the weakened plane or "dummy" type shall be constructed in a manner similar to that provided for dummy joints for longitudinal joints, except that such joints shall be provided with slip dowels or other load transfer devices of the type, size, and arrangement shown on the plans.

50. Weakened plane warping joints

Weakened plane warping joints, when specified, shall be constructed in the locations shown on the plans and in the same manner as the weakened plane contraction joints, except that the load transfer devices shall be omitted and the pavement reinforcing shall extend through the joint.

51. Transverse construction joints

Unless other prescribed joints occur at the same points, transverse construction joints shall be made at the end of each day's run or where interruption of more than 30 minutes occur in the concreting operations.

Transverse construction joints shall not be formed so as to make a slab less than 10 ft in length and if sufficient concrete is not mixed to form a slab at least 10 ft in length, the joints shall be formed at the preceeding joint location and the excess concrete disposed of as directed by the Engineer.

The spacing of subsequent transverse joints shall be measured from the transverse construction joint last placed.

52. Transverse weakened plane joints—base course

Concrete bases shall be provided with expansion and/or contraction joints, and shall be constructed in accordance with provisions of these specifications for constructing similar joints in concrete surface courses.

Note: For bases it is especially important to reduce the interval between joints by means of closely spaced contraction joints so as to control the amount of joint opening (which may extend through the surface course) due to shrinkage and contraction. Experience indicates that the best results are obtained when the spacing of such joints does not exceed 20 ft. Preferably the spacing should not exceed 15 ft.

53. Load transfer devices

(*a*) Dowel bars at least ¾ in. in diameter, 16 in. long, spaced at 12 in. center to center, or other approved type of load transfer device shall be placed across all transverse joints, except warping joints, in the manner shown on the plans. Dowels shall be placed at the middle of the slab depth and held rigidly in proper horizontal and vertical alignment by an approved dowel assembly device to be left permanently in place. A tolerance of not more than 1 in 48 from the correct alignment will be permitted.

(*b*) Dowel coating. The free or unbonded end of each dowel shall be painted with one coat of red lead or basic sulfate blue lead paint at the site of the work. When the paint has dried, the free end of each bar shall be thoroughly coated with heavy oil immediately before it is placed in position. The free end of the dowel bars across expansion joints shall be provided with a metal dowel sleeve conforming to the dimensions shown on the plans, or as approved by the Engineer.

54. Installation of joints

(*a*) If the paving mixer is operated from the shoulder, the joints shall be set immediately after the final testing of the subgrade. If the paving mixer is operated from the subgrade, the joints shall be set immediately after it moves forward, so as to permit as much time as possible for proper installation.

(*b*) The assembled joint shall be put in place on the prepared subgrade. It shall be placed at right angles to the centerline of the pavement. The top of the joint shall be set at the proper distance below the pavement surface and the elevation checked by a properly designed templet. On widened curves, the longitudinal center joint shall be placed so that it will be, as nearly as possible, equidistant from the edges of the slab. The joint shall be set to the required line and grade and shall be securely held in the required position by stakes or an approved installing device or both during the placing and finishing of the concrete. Joints shall be installed so that the concrete pressure will not disturb their alignment. The joints shall be vertical and no joint shall deviate more than ¼ in. in horizontal alignment either way from a straight line. If joints are constructed in sections, there shall be no offsets between adjacent units. Dowel bars shall be checked for exact position and alignment as soon as the joint is staked in place on the subgrade and the joint shall be tested to determine whether it is firmly supported. Any joint not firmly supported shall be reset.

55. Joint fillers

(*a*) Joint filler and material for sealing joints shall conform to the requirements of the specifications and special provisions.

(*b*) The top of expansion joints and all edged joints shall be sealed with the specified filler before traffic is permitted on the pavement. The joint opening shall be thoroughly cleaned of all foreign matter before the sealing material is placed. All contact faces of the joint shall be cleaned with a wire brush to remove loose material, and shall be surface dried when the filler is poured.

(*c*) The filler shall be poured into the joint opening to conform to the details shown on the plans or as directed by the Engineer. The pouring shall be done in such a manner that the material will not be spilled on the exposed surfaces of the concrete. Any excess filler on the surface of the concrete pavement shall be removed immediately and the pavement surface cleaned.

(*d*) When required to prevent tackiness or pickup under traffic, the exposed surfaces of the filler shall be dusted with hydrated lime. Other methods of preventing pickup under traffic may be used when approved by the Engineer.

(*e*) Poured fillers shall not be placed when the air temperature in the shade is less than 50 F except by the approval of the Engineer.

56. Placing reinforcement

(*a*) Steel reinforcement shall consist of welded wire fabric or bar mats in accordance with Section 6 of these specifications. Reinforcing steel shall be free from dirt, scale, or other foreign matter, and rust of such degree of development as to impair bond of the steel with the concrete.

(*b*) When bar assemblies are shown on the plans, the reinforcement bars shall be firmly fastened together at all intersections. Adjacent ends shall lap not less than 20 diameters.

(*c*) Where bars are fabricated into mat form by positive welding at all intersections, the lap may be of such length as will permit cross bars to overlap each other by at least 2 in. The same requirements apply to end laps and side laps.

(*d*) Steel fabric sheets shall be lapped and shall clear all edges of the slab, as shown on the plans. Where steel fabric is used, the concrete shall be struck off by means of a template at the indicated depth of the reinforcing below the finished surface of the slab.

(*e*) Reinforced concrete shall be placed in two operations. The initial pour shall be uniformly struck off 2 in. below the proposed surface of the pavement unless otherwise shown on the plans, and the reinforcement placed thereon. The concrete shall be struck off to the entire width of the pour and a sufficient length to permit the sheet or mat of reinforcement to be laid full length on the concrete in its final position as shown on the plans, without further manipulation of the reinforcement. Adjacent sheets shall be lapped as provided on the plans. The balance of the required concrete shall be placed on the reinforcement. Displacement of the reinforcement during concrete operations shall be prevented.

PLACING AND FINISHING CONCRETE

57. General

(*a*) Concrete shall be distributed to such depth, above grade, that when consolidated and finished, the specified slab thickness will be obtained at all points and the surface will not be below the grade specified for the finished surface at any point.

(*b*) The concrete shall be deposited on the subgrade in such manner as to require as little rehandling as possible. It shall be thoroughly consolidated against and along the faces of the forms. Necessary hand spreading shall be done with shovels, not with rakes. Workmen shall not be allowed to walk in the concrete with boots or shoes covered with earth or other foreign substances.

(*c*) Concrete shall be placed only on subgrade which has been prepared as specified and approved. At all times during operations, at least 300 ft of subgrade shall have been prepared ahead of the mixer. Concrete shall not be placed on a frozen subgrade. No concrete shall be placed around manholes or other structures until they have been brought to the required grade and alignment.

(*d*) Pavement less than 30 ft wide may be constructed either to its full width in a single construction operation or in lanes, unless one or the other method is expressly stipulated on the plans. Pavement more than 30 ft wide shall not be constructed in a single operation. When pavement is constructed in separate lanes, the junction line shall not deviate from the true line shown on the plans by more than ½ in. at any point.

(*e*) Retempering concrete by adding water or by other means will not be permitted.

58. Placing and finishing concrete at joints

(*a*) Concrete shall be deposited on the subgrade as near to the expansion and contraction joints as possible without touching them. It shall then be shoveled against both sides of the joint simultaneously, maintaining equal pressure on both sides. It shall be deposited to a height of approximately 2 in. more than the depth of the joint, care being taken that it is worked under the load transfer devices. The concrete shall not be dumped from the discharge bucket of the mixer directly upon or against the joints, nor shall it be shoveled or dropped directly on top of the load transfer devices. In placing the concrete against expansion and contraction joints and in operating a vibrator adjacent to them, workmen shall avoid stepping upon or disturbing in any way the joints or load transfer devices, either before or after they are covered with concrete.

(*b*) The concrete adjacent to the joint shall be compacted with a vibrator inserted in the concrete and worked along the entire length and on both sides of the joint. The vibrator shall not come in contact with the joint, the load transfer devices, or the subgrade. If any of the dowel bars are displaced, they shall be realigned before the finishing machine passes over them.

(*c*) After the concrete has been vibrated, the finishing machine shall be moved forward until the front screed is approximately 8 in. from the joint. Segregated coarse aggregate shall be removed from both sides of and off the joint. The screed shall be lifted and brought directly above the joint, set upon it, and the forward motion of the finishing machine shall be resumed. When the second screed is close enough to permit the excess mortar in front of it to flow over the joint, it shall be lifted and carried over the joint. Thereafter, the finishing machine may be run over the joint without lifting the screeds, provided there is no segregated coarse aggregate immediately between the joint and the screed or on top of the joint.

(*d*) After the concrete has been placed on both sides of the joint and struck off, the installing bar or channel cap shall be slowly and carefully withdrawn leaving the premolded filler in place. After the installing bar or channel cap is completely withdrawn the concrete shall be carefully spaded and additional freshly mixed concrete worked into any depressions left by the removal of the installing bar. The installing bar shall be cleaned and reoiled prior to each installation of a joint.

Immediately after all finishing operations, including brooming, have been completed and before the concrete has taken its initial set, it shall be edged adjacent to all expansion and contraction joints. Care shall be used to remove any concrete which may be over the premolded joint material. The edging tool shall be so manipulated that a well-defined, continuous radius is produced and a smooth, dense mortar finish obtained. The edging tool shall not be tilted while being manipulated.

After the removal of the side forms, the ends of premolded transverse joints at the edges of the pavement shall be carefully opened for the entire depth of the slab, and in the case of air cushion joints any concrete that has been deposited over the end closure shall be removed, care being taken not to injure the ends of the joint. After the curing period and before the pavement is opened to traffic, premolded joints shall be sealed or topped out, leaving a neat uniform strip of an approved filler material.

59. Finishing methods

(*a*) *Machine finishing*—The concrete as soon as placed shall be struck off and screeded by an approved finishing machine to the crown and cross section shown on the plans and to an elevation slightly above grade that so when properly consolidated and finished the surface of the pavement will be at the exact grade elevation indicated on the plans and free from porous places. The finishing machine shall be of the screeding and troweling type, equipped with two independently operated screeds, designed and operated to strike off the concrete. The machine shall go over each area of pavement as many times and at such intervals as is necessary to give the proper compaction and to leave a surface uniform texture, true to grade and crown. Excessive operation over a given area shall be avoided. The last trip for a given area shall be a continuous run of at least 40 ft. The tops of the forms shall be kept clean by an effective device attached to the machine and the travel of the

machine on the forms shall be maintained true without lift, wobbling, or other variation tending to affect the precision of finish. The finishing machine shall be of ample strength to withstand severe use and shall be fully and accurately adjustable for loss of crown or other derangement due to wear.

During the first pass of the finishing machine a uniform ridge of concrete at least 3 in. deep shall be maintained ahead of the front screed for its entire length. Except when making a construction joint, the finishing machine shall not be operated beyond that point where the above described surplus can be maintained ahead of the front screed.

(*b*) *Vibrated finishing*—When vibrated finishing is required by the special provisions, the finishing machine shall be equipped for applying high-frequency vibration to the upper surface of the concrete in accordance with the requirements for either of the following types. The particular type selected by the Contractor shall be subject to approval of the Engineer. The vibratory units shall be synchronized and shall operate at a frequency of not less than 3500 cycles per minute.

1. *Vibrating units mounted directly on the screeds*—This type shall consist of two independently operated screeds. The front screed shall be equipped with not less than one vibrating unit for each 7½ ft length or portion thereof of vibratory screed. The front screed shall be not less than 15 in. wide and shall be equipped with a bull-nose front edge having a radius of not less than 2 in.

2. *Vibrating pan mounted independently of the screeds*—This type shall consist of two independently operated screeds together with an independently operated vibratory pan (or pans). The pan shall be mounted in such a manner as not to come in contact with the forms. It shall rest directly on the concrete and shall be so adjusted as to produce uniform vibration over the entire width of pavement surface. The pan shall be equipped with not less than one unit for each 7½ ft of length or portion thereof of vibrating pan. The screeds shall be capable of operating in a position that will strike off the concrete at a sufficient height above the top of the forms to allow for proper compaction with the vibratory pan.

(*c*) *Floating*—As soon as possible, after the concrete has been struck off and consolidated, it shall be further smoothed and consolidated by means of a longitudinal float of a suitable design approved by the Engineer. In this operation, the longitudinal float shall be worked with a sawing motion, while held in a floating position parallel to the road centerline and passed gradually from one side of the pavement to the other. Movements ahead along the centerline of the road shall be in succesive advances of not more than one-half the length of the float.

(*d*) *Straightedging*—After the longitudinal floating has been completed and the excess water removed, but while the concrete is still plastic, the slab surface shall be tested for trueness with a 10-ft straightedge swung from handles 3 ft longer than one-half the width of the slab. The straightedge shall be held in successive positions parallel to the road centerline in contact with the surface and the whole area gone over from one side of the slab to the other. Advance along the road shall be in successive stages of not more than one-half length of the straightedge. Any depressions found shall be filled immediately with freshly mixed concrete, struck off, consolidated and refinished. High areas shall be cut down and refinished. The straightedge

testing and refloating shall continue until the entire surface is found to be free from observable departures from the straightedge and the slab has the required grade and crown.

(*e*) *Belting*—After straightedging when most of the water sheen has disappeared and just before the concrete becomes nonplastic, the surface shall be belted with a two-ply canvas belt not less than 8 in. wide and at least 3 ft longer than the width of the slab, or with an approved wooden belt. Hand belts shall have suitable handles to permit controlled uniform manipulation. The belt shall be operated with short strokes transverse to the road centerline and with a rapid advance parallel to the centerline.

(*f*) *Brooming*—After belting and as soon as surplus water has risen to the surface, the pavement shall be given a broom finish with an approved steel or fiber broom, not less than 18 in. wide. The broom shall be pulled gently over the surface of the pavement from edge to edge. Adjacent strokes shall be slightly overlapped. Brooming shall be perpendicular to the centerline of the pavement and so executed that the corrugations thus produced will be uniform in character and width, and not more than ⅛ in. deep. The broomed surface shall be free from porous spots, irregularities, depressions and small pockets or rough spots such as may be caused by accidentally disturbing particles of coarse aggregate, embodied near the surface. Brooming will not be required for concrete bases.

(*g*) *Edging*—After belting and brooming have been completed, but before the concrete has taken its initial set, the edges of the slab shall be carefully finished with an edger of the radius required by the plans.

(*h*) *Final surface test*—The Contractor will be held responsible for the correct alignment, grade, and contour specified. Any spots higher than ⅛ in. and not higher than ¼ in. for concrete pavements and higher than ¼ in. for concrete bases but not higher than ⅜ in. above the correct surface as shown by the 10-ft straightedge, shall be ground to the required surface by the Contractor at his own expense. Where deviation exceeds the foregoing limits, the pavement slab shall be removed and replaced by the Contractor at his own expense, as directed by the Engineer.

60. Cold weather concreting

(*a*) Except by specific written authorization, concrete placing shall cease when the descending air temperature in the shade and away from artificial heat falls below 40 F. It shall not be resumed until the ascending air temperature in the shade and away from artificial heat rises to 35 F.

(*b*) When concreting is permitted during cold weather the temperature of the mixed concrete shall be not less than 60 F nor more than 100 F at the time of placing in the forms. The aggregates or water or both may be heated. The aggregates may be heated by steam or dry heat prior to being placed in the mixer. The water shall not be hotter than 175 F; aggregates shall not be used which are hotter than 150 F.

(*c*) When concrete is being placed during cold weather and the air temperature may be expected to drop below 35 F, a supply of straw, hay, grass or

other suitable blanketing material shall be provided along the line of the work. At any other time when the air temperature may be expected to reach the freezing point during the day or night the material so provided shall be spread over the concrete to a sufficient depth to prevent freezing of the concrete. Such protection shall be maintained for at least 5 days. If required by the Engineer, concrete less than 24 hours old shall also be covered by approved canvas or similar enclosures and devices capable of maintaining the temperature within the concrete at 50 F or higher. Concrete injured by frost action shall be removed and replaced at the Contractor's expense.

61. Lighting conditions

When the natural light is insufficient for proper work, operations shall cease unless approved artificial lighting is provided.

CURING

62. Preliminary curing period

The concrete shall be covered with two thicknesses of wet burlap weighing not less than 7 oz per sq yd, cotton mats, or other approved material of highly absorptive quality, immediately after final finishing of the pavement surface. The material shall be kept saturated by spraying and shall remain in place for at least 12 hours.

63. Final curing

For completion of the curing the mats used for the preliminary curing period may be left in place and kept saturated for 72 hours, or they may be removed at the end of the preliminary curing period and the concrete surface protected by keeping the surface covered with water (ponding) for 3 days after placing of the concrete; or by a 1-in. layer of thoroughly wet earth, or sand, or a 6-in. layer of thoroughly wet straw, hay or similar material maintained on the surface of the concrete and kept thoroughly wet for 3 days after placing of the concrete. Other methods of final curing may be used if approved by the Engineer. The sides of concrete slabs exposed by the removal of forms shall be protected immediately after the removal of the forms in such a manner as to provide these surfaces with a curing treatment equivalent to that provided by the method prescribed for the surface.

MISCELLANEOUS

64. Pavement thickness

(*a*) The thickness of the pavement shall be determined by measuring the lengths of drilled concrete cores according to the procedure of the current A.S.T.M. Standard Method of Measuring Length of Drilled Concrete Cores (Designation C 174). At such points as the Engineer may select, in each 1000 linear ft of pavement, 2 or more cores shall be taken and measured. The average thickness of each mile of slab, or fractional mile, will be determined from these measurements.

(*b*) Pavement of which the average thickness is within $\frac{1}{2}$ in. of the thickness required by the typical cross section shown on the plans, will be accepted and paid for at the contract price.

(*c*) For pavement, the average thickness of which is less than the thickness shown on the plans by more than ⅛ in. but by less than ½ in., an adjusted unit price shall be used in payment. This price shall bear the same ratio to the contract unit price as the square of the average thickness of the slab bears to the square of the thickness specified on the plans.

(*d*) Payment will not be made for pavement which is found deficient in thickness by ½ in. or more. Such pavement shall be removed and replaced by the Contractor with pavement of the specified thickness at his expense. When the measurement of any core indicates that the slab is deficient in thickness by ½ in. or more, determination shall be made of the thickness of transverse sections of the slab at 25 ft intervals set off along the centerline of the road in each direction from the affected location until a transverse section of the slab is found which is not deficient in thickness by as much as ½ in. The area of pavement for which no payment will be made shall be the product of the width of pavement multiplied by the distance along the centerline of the road between the transverse sections found not deficient in thickness by as much as ½ in. If the Contractor is not satisfied, he may request additional cores and measurements. Such measurement shall be made at intervals of not less than 200 ft. The cost of additional cores and measurements shall be deducted from any sums due the Contractor unless the measurements indicate that the slab within the area in question is of specified thickness.

(*e*) No additional payment over the unit contract price bid will be made for pavement found to be thicker than the specified amount.

65. Protection of finished pavement

(*a*) The Contractor shall erect and maintain suitable barricades and, when required in the special provisions, shall employ watchmen to exclude traffic from the newly constructed pavement until open for use. These barriers shall be so arranged as not to interfere with public traffic on any lane intended to be kept open, and necessary signs and lights shall be maintained by the Contractor clearly indicating any lanes open to the public. Where, as shown on the plans or indicated in the special provisions, it is necessary to provide for traffic across the pavement, the Contractor shall at his expense construct suitable and substantial crossings to bridge over the concrete.

(*b*) Any part of the pavement damaged by traffic or other causes prior to its final acceptance shall be repaired or replaced by and at the expense of the Contractor in a manner satisfactory to the Engineer. The Contractor shall protect the pavement against both public traffic and traffic of his employees and agents.

66. Public use of thoroughfare

(*a*) Normal, unimpeded use of the thoroughfare of which the proposed pavement is to be a unit, is of value to the public. It is, therefore, mutually understood, that for the sections of the thoroughfare identified on the plans as requiring special traffic handling and for the distances stated thereon,

surfaced road lanes as indicated shall be made available by the Contractor for unimpeded public traffic at all times, and maintained in proper condition throughout the construction period. These lanes shall be of the clear widths stated on the plans, and shall be kept entirely free from encroachment by equipment of the Contractor, by workmen or employees of the Contractor or by storage or transportation of materials intended for the work.

(*b*) The scheme and sequence of construction of the several lanes, slabs and sections of pavement, including the sequence of the shifting of public lanes during progress of construction, shall be as given on the plans or as described in the special provisions.

(*c*) Where the edge of any stipulated public traffic lane is contiguous to an edge of the slab or lane being placed, the Contractor shall provide, erect and subsequently remove, a substantial temporary guard fence, as shown on the plans along the prescribed dividing line, which shall be maintained there until the slab is opened to traffic. The Contractor's plan of operation shall be such as to obviate any need for encroachment on the public traffic lane or lanes. Where so shown on the plans, special lanes for the Contractor's trucks and similar vehicles shall be provided, separate from and not interfering with the prescribed traffic lanes. Where the clearance between public traffic lanes and the Contractor's operating equipment is restricted, special delivering equipment may be necessary, designed to deliver and depart within the width of the slab actually being placed without encroaching any public lane.

(*d*) Except where a special bid price for "traffic handling" is required in the proposal and in the special provisions, all cost of handling and protecting traffic, of special equipment, of temporary road surfacing and its maintenance, of temporary guard fences and of other things to be provided or to be done under this paragraph, shall be at the expense of the Contractor.

67. Opening to traffic

Traffic will ordinarily be excluded from the newly constructed pavement for 7 days after the concrete is placed and may be excluded for a longer period if cross-bending tests indicate its advisability. Cross-bending test specimens, prepared at regular intervals from the concrete as it comes from the mixer and cured under the same temperature, moisture and climatic conditions as the corresponding slabs of pavement, shall be employed as a means of fixing the time of opening the pavement to traffic. These beams shall be made and tested in accordance with Section 13. When tests of these specimens indicate that the corresponding pavement has attained a modulus of rupture of at least 450 psi the pavement shall be cleaned, the joints filled and trimmed and the pavement opened to traffic. If this strength is not attained within 7 days, the Engineer may open the pavement to traffic at his discretion. The joint or line of separation between adjacent strips or slabs of concrete, when the pavement is constructed in strips or slabs shall be cleaned and filled with an approved sealing material.

Discussion of a report of Committee 617:

Specifications for Concrete Pavements and Bases (ACI 617-51)*

By C. C. OLESON, PHILLIP L. MELVILLE and COMMITTEE

By C. C. OLESON†

In a field as broad as the construction of concrete pavements and bases, it is quite difficult to prepare general specifications that will meet with complete general approval. Local conditions introduce special problems that can only be covered by special provisions, often conflicting directly with the clauses in the general specifications. Although this is unavoidable, it is covered by the statement that in case of conflict, the special provisions will govern. However, there should be no conflicting statements in the general specifications themselves, and every effort should be made to avoid ambiguities. Past experience has shown how quickly faults in specification will be revealed after they have been published and adapted to specific use.

The ACI specifications are the joint effort of a very competent and experienced group of engineers. The writer is extremely hesitant in attempting to point to apparent inconsistencies and omissions in them, but believes that they will eventually be uncovered, so why not now? The following items are discussed in the order in which they appear in the specifications.

Burlap

In Par. 10(a), it states that burlap "shall weigh not less than 7 oz. per sq. yd. when clean and dry." Par. 62 states, "two thickness of wet burlap weighing not less than 7 oz. per sq. yd. . ." The apparent ambiguity would be removed by deleting the last portion of the sentence in Par. 62, beginning with "weighing."

Bulk specific gravity

In Par. 13(a),(b), the density of aggregates is described as "bulk specific gravity", which according to ASTM C 127 and 128 is the *oven dry weight* divided by *saturated surface dry weight* minus the weight of the saturated sample in water. Under Table 1, a footnote describes the bulk specific gravities as "all in saturated, surface dry condition." It would clarify the specifications to add "Saturated and surface dry" to bulk specific gravity in Par. 13(a) and (b), since that is apparently what is intended.

*ACI JOURNAL, May 1951, *Proc.* V. 47, p. 721. Disc. 47-49 is a part of copyrighted JOURNAL OF THE AMERICAN CONCRETE INSTITUTE, V. 23, No. 4, Dec. 1951, *Proceedings* V. 47.

†Principal Research Engineer, Portland Cement Assn., Chicago, Ill.

Table 1

In Table 1 the column "Cement, bags per cu yd" is misleading. Total weights of aggregates are listed as the same for gravel and crushed stone, but the crushed stone is allowed 0.6 gal. of water per sack more than is allowed for gravel. Ignoring any reference to the merits of this differential, it simply means that for every one-sack batch, the yield for crushed stone is 0.6 / 7.5 = 0.08 cu ft more than for gravel. Absolute volume computations show that for plain, machine finished, gravel concrete, 6.19 sacks of cement are required for a cu yd of air-free concrete, compared with 6.10 bags per cu yd of air-free crushed stone concrete. Admitting that footnote No. 3 is supposed to take care of it, why not equalize the quantities by adding $0.08 \times 165 =$ 13 lb to the gravel aggregate quantities in the table. 180:145:220 would do it in the first line; the 4th, 7th and 10th lines could be adjusted similarly. The yields would then be theoretically the same.

Joints

Par. 45(c) states "the surface . . . shall be finished to a true plane . . ." This generally is a physical impossibility, because there is usually a pronounced parabolic crown to most tangent sections of pavement. Omit the words "finished to a true plane," and the requirements are as intended.

Transverse joints

Apparently the committee does not favor either flexible ribbon or sawed joints. Joints that are formed in the plastic concrete with a grooving tool *can be*, and often are, much poorer than the other two types.

It is a bit surprising that no reference is made to the use of mechanical spreaders as the first operation after concrete is placed on the subgrade. Since it is now a widely-used practice to employ a mechanical spreader, it would seem that this important piece of equipment should rate a paragraph, including some recommendations or restrictions as to its use.

Par. 57(e) seems a bit unrealistic. "Retempering" may be bad, but what happens when a surface dries out before it is finished? Which is the lesser of two evils, to add enough water to restore the plasticity that should be there anyway, and without which the surface cannot be properly finished; or to leave the surface rough and grind it smooth later on? At any rate, this form of retempering is being done on most paving jobs, and will continue to be done in spite of specifications to the contrary. Why not say, "In an emergency and for restricted areas, it is permissible to restore surface plasticity by spraying lightly, or sprinkling with just enough water to permit necessary finishing operations."

Floating

The words "as soon as possible" are more or less meaningless and can cause a lot of argument between contractor and engineer. The longitudinal float *can be* operated immediately following the transverse finisher, but it may not serve its intended purpose at this location except in isolated cases. Its relative location behind the finisher should depend upon bleeding charac-

teristics of the concrete. For nonbleeders, the float will be close to the finisher. For moderate or heavy bleeders, the float may be as much as 400 ft behind the finisher without being too far behind. This is a very important finishing operation, and should be carefully controlled. Theoretically it removes excess surface water and consolidates while shaping both longitudinally and transversely. In practice this seems to be most effectively accomplished *at the moment when bleeding is checked*, and not before.

Straightedging

Straightedges are frequently (and quite satisfactorily) used as finishing tools. Possibly this function should be recognized and controlled to some extent—or prohibited entirely. Simply checking for irregularities frequently leaves longitudinal marks every place the edge touches the surface. Using the straightedge blade as a narrow elongated float or trowel can be a big help in removing laitance that may have accumulated and in taking off the bumps that normal straightedging might miss.

Brooming

Par. 59(f) infers that a single broom should be used, "Pulled gently over the surface from edge to edge." This would require a handle nearly 30 ft long for a 24 ft slab, and that is a lot of handle. The writer does not recall of ever seeing brooming done in this manner. Generally each half is broomed separately from *center to edge*, using separate brooms on each side.

Lighting

In Par. 61, it would seem that the specification is apt to catch a contractor with some unfinished concrete. Would it not be more appropriate to say "satisfactory and adequate artificial lighting *shall be provided* for any operation that is performed after natural light becomes insufficient for proper work." It isn't logical to stop work before it is done, simply because night falls and lights are not available.

Curing

It is evident that the committee does not concur with Mr. Swayze* on curing. He says, "damp burlap or other curing mats should therefore be applied, but should contain no free water which can be absorbed by the concrete until maximum compaction of the surface has been obtained." He concludes, "only enough water should be supplied to keep the covering moist." This procedure is now being followed deliberately in some states, and is probably practiced in many other states where *saturated* burlap is specified.

By PHILLIP L. MELVILLE†

ACI Committee 617 under the able chairmanship of H. F. Clemmer completed a laudable revision of the Standard Specifications for Concrete Pavements and Bases. Its ratification by letter ballot of the membership is an

*Swayze, Myron A., "Early Concrete Volume Changes and Their Control," ACI JOURNAL, Apr. 1942, *Proc.* V. 38, pp. 425-440.

†Associate Research Engineer, Council of Highway Investigation and Research, Commonwealth of Virginia, Charlottesville.

indication of the quality of the report. The writer wishes, nevertheless, to record his dissent to some of the statements made on high-early strength concrete (p. 729) under Par. 23. The following remarks are based on a study of high-early strength concrete made by the Virginia Council of Highway Investigation and Research at the University upon request of the Department of Highways.

The Committee goes on record as favoring the use of Type III cement to obtain high early strength. The American Road Builders' Assn. made a nation-wide survey of concrete construction practices of the various highway departments in 1947* and again in 1949.† A perusal of the reports indicates that while 61 percent of the states permitted use of Type III cement in 1947 and 63 percent in 1949, 45 percent permitted the use of additional portland cement (Type I, IA, II or IIA as the case may be) in 1947 and over 53 percent did so in 1949. In addition some 10 percent allowed the use of calcium chloride.

The practice of increasing the cement factor seems to be gaining favor and to clarify the situation the Council canvassed a number of state highway materials or testing engineers. Exceptions taken to the use of Type III cement far outweighed objections to the use of an increased factor. In the order of frequency in which they were formulated the exceptions were as follows:

1. Lower ultimate strengths.
2. Early disintegration.
3. Flash set.
4. Excessive cracking.
5. Excessive heat of hydration.
6. Lighter color.
7. Inconvenience to contractor.

Such views corroborate experience in Virginia with Type III cement. In 1947, R. L. Sheppe‡ made a survey of 438 miles of concrete pavement in the Commonwealth built between 1923 and 1946. Projects constructed with high-early strength cements showed "a considerable amount of cracking." Mr. Sheppe further stated that "some projects built entirely of high-early strength cement showed signs of deterioration not usually found in other pavements of comparative age."

It should also be noted that an increased cement factor is often no more expensive (and sometime more economical) a method of obtaining early strength than the use of Type III cement. This is particularly true if extrinsic values—such as convenience to the contractor—are taken into account.

Results of series of tests performed in the concrete laboratory of the Council using sundry State-approved aggregates and cement types and brands, in various combinations, are also in conflict with the recommendations of Committee 617. The data are too bulky to be presented in its entirety in this

*American Road Builders' Association "Report of Committee on Concrete Pavement Design," *Bulletin 121*, 1947.
†Ibid, *Bulletin 163*, 1949.
‡Sheppe, R. L., "Reconnaisance of Portland Cement Pavements in Virginia," *Progress Report No. 1*, Unpublished, Virginia Dept. of Highways, June 1947.

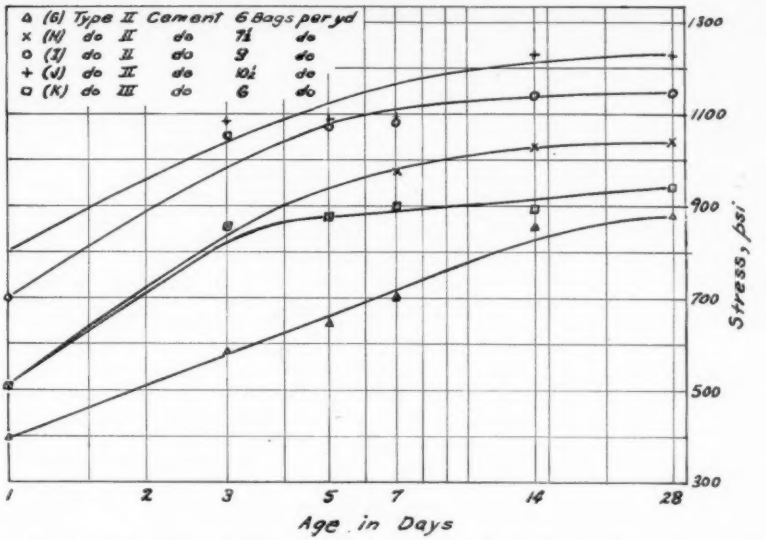


Fig. A—Tests in flexure of 3 x 3 x 16-in. beams, center point loading on 9-in. span. Each point an average of four tests.

discussion. An excerpt is presented in graphic form for a typical group of materials in Fig. A.

In accordance with *Virginia Road and Bridge Specifications* a pavement shall be opened to traffic when "cross-bending test specimens . . . . tested by standard methods, AASHO T 97-42 . . . . indicate that . . . . the corresponding pavement has attained a modulus of rupture of not less than five hundred fifty pounds per square inch."

When high-early strength portland cement is used the flexural strength of 550 psi is to be attained in 48 hours. Fig. A indicates that an average use of eight bags of normal cement is to be prescribed to obtain a high early strength at least equal to that of Type III cement in conflict with a specified limitation of the Committee to seven bags of cement per cu yd of concrete. A similar conclusion was reached in regard to "structural" concrete.

Furthermore the Highway Research Board* has offered recommendations in direct conflict with the seven bag limit quoted above. The Board offers standard designs "to yield concrete slightly better in quality than that specified by the American Association of State Highway Officials for concrete strength of 550 psi at 14 days" and suggests the use of eight bags of "normal" cement per cu yd if the pavement is opened to traffic at the age of three days.

It has often been stated that a concrete having more than seven bags of cement per yard is not durable due to the resulting high heat of hydration

*"Patching Concrete Pavements with Concrete," *Wartime Road Problems*, Highway Research Board, No. 6, July 1943.

and large volume changes. To have some information on that item, the Council undertook a limited study of durability as evaluated by variations in sonic moduli resulting from cycles of wet thawing—dry freezing as commonly used by a number of laboratories. Again the data are lengthly but the results may be abstracted as follows for the concrete mixes investigated.

1. Durability decreased as the cement factor increased.
2. For mixes intended to yield the same high early strength, the increased cement factor mix always had superior durability to the mix containing Type III cement.

In conclusion the writer feels that the use of additional portland cement to obtain high-early strength concrete may have been rather unjustly frowned upon by the committee and the ban on certain mixes containing more than seven bags of cement per cu yd does not appear to be practical and justified.

COMMITTEE CLOSURE

The committee appreciates the discussions presented. It is gratifying to know that a study has been made of the specification by such competent engineers and it is believed that readers will benefit from the discussions and this closure since some points will be clarified in so doing.

The committee agrees with some of the suggested changes in the specifications and will include them in the next general revision of the Standard; other points require further study but will be considered in the light of current practices at that time.

The committee is in full accord with deleting the portion of the sentence in Par. 62 ". . . weighing not less than 7 oz per sq yd . . ." for clarification purposes.

The committee does not believe it necessary to add "Saturated and surface dry" to the bulk specific gravity in Par. 13(a) and (b) since it is stated under Table No. 1 that the saturated surface dry condition has been used in computing the table. This is one of the formulas presented in ASTM 127.

It is agreed that Table 1 may be confusing and to circumvent this the committee will suggest adding the word "Approximate" to the column headed "Quantities of materials . . . " and adding to the first sentence of Par. 19 the words "water demand, particle shape, etc." It is further suggested that the symbolism indicated in Table 1 might be general and not refer to specific portions of the table.

The committee agrees that the words "finished to a true plane" should be stricken from Par. 45(c).

The use of a flexible ribbon, sawed joints and a finishing machine will be taken under advisement in the next general revision of the specification.

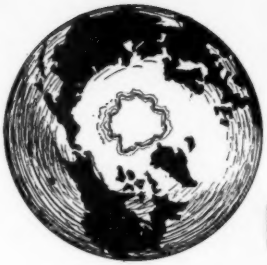
The committee appreciates the comments regarding retempering but does not believe it advisable to sanction the process of retempering concrete even though it recognizes that this procedure as well as other malpractices are unfortunately not uncommon.

It will be recommended that the word "possible" be changed to "practicable" in Par. 59(c).

The intent of the specification is not to prohibit the use of the straightedge as a finishing tool in Par. 59(d). However, it is the concensus that it should not be referred to as such.

The questions raised as to brooming, artificial lighting, curing practices, and increasing the cement factor for high-early strengths will be taken into consideration when the next general revision is accomplished. It is believed that these items as presented in the present specification are adequate and changes at present are not warranted.

The committee has not treated lightly the suggestions of Oleson and Melville. Some of the points raised were deliberated when the present specification was prepared; however, current practice and thinking at the time of preparation was the intent of the committee. In light of the discussion the committee believes that points now clarified will make for a better specification.



Letters from Readers*

BY WAY OF SYNOPSIS

L. Boyd Mercer lists 60 contributory causes of variations in concrete compression tests.

Floor deterioration caused by sodium polyphosphate causes trouble for a Reader.

Lester C. Kirkpatrick suggests that air-entraining agents be packaged in capsules to facilitate adding the correct dosage to mixes.

Charles F. Peck, Jr., and David S. Steiner note that mixer design should be evaluated with respect to variation in quality of concrete produced.

Henry J. Cowan adds to the discussion regarding the plastic theory of design.

F. N. Menefee believes that ACI and others have already established "signposts" to guide the development of prestressed concrete, although some of the directions are not too clear.

A Reader adds 11 to concrete's etymological offspring.

Concrete Strength Variations—60 Contributory Causes (LR 47-80)

"Is the compression test for determining quality of concrete obsolete?" This was one of many questions asked the panel at the annual convention in San Francisco. L. Boyd Mercer surveyed the factors involved in the compression test in the Mar. 28, 1950, *Building and Construction*, Australia. Permission has been granted to reprint portions of the paper, which should prove of interest to technologists concerned with testing concrete specimens.—Editor

Is the compression test for determining quality of concrete obsolete? This question is indicative of increasing dissatisfaction with the common standard method for testing concrete.

Principal objections to the compression test are the delay in awaiting results, 7- and 28-day figures having little more than post-mortem value, and also the fact that cracking and similar failures are tensile rather than compressive—resulting in some preference for the beam test in recording flexural modulus.

Moreover, no small amount of dissatisfaction emanates from the excessive variations which arise in compression testing—variations far beyond those directly associated with the quality of concrete in the structure. The apparent simplicity of the test has proved to be its downfall; the necessity for strict attention to all details makes the actual conduct of the test complex with the result that individual tests have little value. Even under complete laboratory control it is

*A part of copyrighted Journal of the American Concrete Institute, V. 22, No. 9, May 1951, *Proceedings* V. 47. Separate prints of the entire Letters from Readers Section are available at 35 cents each. Address 18263 W. McNichols Rd., Detroit 19, Mich.

TABLE 1—SUMMARY OF COMPRESSION STRENGTH TEST VARIABLES

No.	Basic cause	Cause of variation	Probable occurrence	Effect
1	Cement, material	Type and composition	With different brands	Considerable variation
2	Cement, material	Manufacturing control	Any one brand	Can be considerable
3	Cement, material	Age and condition	Always possible	Considerable variation
4	Water	Presence of salts	Infrequent	Not generally great
5	Water	Water-cement ratio	Dependent on control	Major effect
6	Sand, material	Chemically reactive	Common minor fault	Can be considerable
7	Sand, material	Unsound particles	Infrequent	Not general
8	Sand, material	Nonuniform properties	Infrequent	Not general
9	Sand, material	Clean	Common minor fault	Not generally great
10	Sand, material	Particle shape	Crusher and natural	Not within one type
11	Sand, material	Grading	Always present	Through workability
12	Stone, material	Chemically reactive	Uncommon	Not appreciable
13	Stone, material	Unsound particles	Dependent on source	Not generally great
14	Stone, material	Nonuniform properties	With porous material	Not generally experienced
15	Stone, material	Clean	Always possible	Can be considerable
16	Stone, material	Particle shape	Crusher and natural	Not within one type
17	Stone, material	Grading	Always present	Through workability
18	Stone, material	Maximum size	With different mixes	Through workability
19	Temperature	Cement	Hot cement	Not appreciable
20	Temperature	Water	Extremes of climate	Not generally experienced
21	Temperature	Aggregates	Extremes of climate	Not generally experienced
22	Mix	Paste-aggregate change	Deliberate variations	Through workability
23	Cement batching	Errors in weighing	Infrequent	Inconsiderable
24	Cement batching	Volumetric measurement	Frequent	Errors ± 20 percent
25	Water measurement	Directly added water	Where rely on judgment	Not if measured
26	Water measurement	Contained with sand	Most common	Considerable
27	Water measurement	Sand bulking	Volumetric measurement	Can be considerable
28	Water measurement	With coarse aggregate	Over period	Can be considerable
29	Sand measurement	Material changes, bulking	Volumetric measurement	Errors ± 20 percent
30	Stone measurement	Material changes, operation	Where control limited	Not generally great
31	Mixing	Order of charging	Dependent on operator	Generally unimportant
32	Mixing	Priming mix	Occasional only	Can be considerable
33	Mixing	Mixer speed	With different plants	Not general
34	Mixing	Overcharging	Infrequent	Not general
35	Mixing	Time of mixing	Frequent	Variation can exceed 30 percent
36	Handling, sampling	Segregation	Chutes, transportation	Planes of weakness
37	Handling, sampling	Constituent changes	Wherever retemper	Impossible to estimate
38	Handling, sampling	Sampling	Different locations	Can be appreciable
39	Handling, sampling	Bleeding	Mixes with water loss	Not generally great
40	Compaction	Hand tamping	Drier mixes	Considerable, exceed 50 percent
41	Compaction	Vibration	Over vibration	Segregation in specimens
42	Compaction	Shock	Handling after setting	Damage creates weakness
43	Compaction	Particle orientation	Planes of weakness	Flat particles—40 percent
44	Size and shape	Wet screening	Mass concrete	Increase with screening
45	Size and shape	Size of specimen	Nonstandard molds	Decrease strength with size
46	Size and shape	Height-diameter ratio	Nonstandard molds	Decrease as ratio increases
47	Size and shape	Shape	Cube or cylinder	Cube strength greater
48	Size and shape	Mold irregularities	Nonstandard molds	Nonaxial load
49	Curing	Drying out	First 24 hours	Not great
50	Curing	Moist curing	Not job curing	75 percent increase in 10 days
51	Curing	Initial temperature	Freezing conditions	Infrequent
52	Curing	Temperature	Job curing in winter	60 percent variation possible
53	Curing	Age	Compare at same age	Continuous increase
54	Curing	Moisture content	When specimens dry	40 percent difference
55	Capping	Plane ends	Most common fault	Concavity 30 percent, Convexity 50 percent
56	Capping	Capping material	Cement paste difficulty	Plaster of paris—12 percent
57	Capping	Axis of specimen	Technique problem	Not generally great
58	Testing machine	Bearing block	Dependent on laboratory	Can be considerable
59	Testing machine	Centering	Dependent on laboratory	Can be appreciable
60	Testing machine	Speed of loading	Dependent on laboratory	Not generally great

necessary to apply statistical analysis to determine the relative significance of results.

However, the compression test will not be replaced at any early date and hence an appreciation of the factors involved is essential.

Concrete strength variables

The compressive strength of concrete as determined by the preparation and testing of molded specimens is affected by various factors. Some of these factors can be eliminated for any one job or investigation, others

are inherently variable to different degrees dependent upon methods for control and conditions.

(Those factors that influence strength and variations include cement, water, fine and coarse aggregate, temperature, mix properties, batching, water measurement, mixing, handling and sampling, compaction, size and shape of test specimens, curing, capping and application of load by testing machine.—EDITOR)

Explanation of table

Table 1 summarizes the factors which contribute to compressive strength variations. Contributory causes are presented so as to assist in the selection of those capable of providing an explanation for any particular problem of variations. The factors include items which might reasonably be expected to apply to variations between concrete test results for different jobs in different localities, to those which can occur when several test cylinders are taken from the same batch of concrete.

In using the table delete those items which obviously do not apply and then examine the remainder as leading to the desired explanation. Thus in the analysis of test results for a considerable concrete pour extending over a long period and at one location, as say for a dam or airport runway, it may be possible to eliminate immediately many of the material, mixing and test variables—while still leaving individual items in the several groups. In an investigation into differences between a series of specimens for one batch, it would be reasonable to dismiss the first 35 causes of variation listed.

Finally, there can always be several contributory explanations for variations, some of them being cumulative while others cancel and thus present a misleading impression.

L. BOYD MERCER, chief engineer, Ready Mixed Concrete, Ltd., Melbourne, Australia

Floor Deterioration Raises Problem (LR 47-81)

A plant manufacturing sodium polyphosphate, $(NaPO_3)_x$, has a concrete floor which has deteriorated in less than two years to a point where it is unusable and must be replaced. This deterioration began within a few months after the new concrete floor was placed, due to the solvent effect on concrete of the chemical deposit on the floor being washed down with water.

Is there any concrete mix or special surfacing course that would not be affected by sodium polyphosphate? The surfacing must also withstand heavy traffic at temperatures as high as 110 F.

READER

Appendix 1 in the 1940 Joint Committee Report tabulates the effect of various substances on concrete and suggests protective requirements. The table includes petroleum oils, coal-tar distillates, inorganic acids, organic materials, salts, and miscellaneous agents encountered in food processing and industrial operations. However, the table does not mention phosphates.

The panel discussion at the 47th annual convention in San Francisco discussed methods of preventing deterioration of concrete subjected to chemicals used in water treatment, which may prove helpful in solving the problem. Protective treatments that have proved effective in combating attack from iron and aluminum sulfates and phosphates are vinyl resins, coal tar and asphaltic paints.

Additional comments by readers are invited.—EDITOR

Air-Entraining Agents Packaged in "Pill" Form (LR 47-82)

It is often difficult to control the amount of air-entraining agent added to ready-mixed concrete. With varying water contents and aggregate proportions, without a uniform mixture, a nonuniform concrete is the result.

Various methods of controlling air-entraining agent additions have been tried. One method used is to fill a metal container with

the liquid agent. A small pipe, ⅜ to ½ in. diameter, permits the liquid to flow by gravity into the mix. It is not dependable as the pipe often chokes and does not release uniform amounts.

A pump has also been used with little success. It is supposed to inject the proper amount of agent, set by a gage, into the mix. Due to the viscosity of the liquid air-entraining agent, the feed line is choked at first and then releases too much in hot weather, and in cold weather it releases little or none at all.

Since neither of these methods are satisfactory in achieving a uniform mix, the writer suggests that the agent be put in a container similar to a capsule, that would dissolve in water, so that the correct amount could be dropped into the mixer and a uniform batch would be assured. These capsules could be made in several sizes and the required number dropped in the mix, according to the mix design for each batch.

LESTER C. KIRKPATRICK, plant inspector, Alabama State Highway Dept., Birmingham, Ala.

Quality and Uniformity Real Test of a Mixer (LR 47-83)

"Blade Changes Improve Tilting Mixer," by Glenway Maxon, December 1950 JOURNAL, p. 297, advances the knowledge of the effect of mixing time on properties of concrete; knowledge which in the past has been based largely on tests conducted on one type of mixer. The author's study on effect of mixer design on mixing time required to secure a uniform concrete is important since any reduction of mixing time while maintaining production of a uniform concrete of desired quality will be reflected in reduced costs.

Maxon apparently bases changes in mixer design on observation of the pattern of flow of the ingredients. There is, however, no absolute guarantee that a mix will be of high quality simply because it appears to be well mixed. The real test of a concrete mixer lies in the quality and uniformity of quality of batches it produces. Efforts to evaluate mixers by either analysis of mortar samples or visual study of flow of materials within the mixer have overlooked the goal of a uniform final product. While each of these methods has its place in the study of mixing action, it would be worthwhile to evaluate mixer design with respect to variation in quality of the concrete produced by the mixer.

Many standardized test specimens should be cast and tested from a given mixer batch and a frequency distribution curve of compressive strength or any other desired property of specimens drawn. The success of mixing action could then be expressed as a function of the variability of this property. The study of the variation of a property would be useful in describing mixing success but would give no indication of why the variation occurred. It is in this respect that the author's method used with a study of particle size distribution has its greatest value.

CHARLES F. PECK, JR. and DAVID S. STEINER, Dept. of Civil Engineering, Carnegie Institute of Technology, Pittsburgh, Pa.

Skepticism Regarding the Plastic Theory of Design (LR 47-66)*

Hadley's letter is timely because it calls attention to lack of experimental evidence for many of the propositions which have been advanced for design of reinforced concrete structures. However, the condemnation of "plastic" design theories is much too sweeping. He takes no account of the absence of satisfactory evidence to support the elastic working stress theory. The assumptions that concrete is elastic and that the modular ratio is in accordance with some arbitrary rule are far from the truth. This is readily

*See also ACI JOURNAL, Nov. 1950, *Proc.* V. 47, p. 257; Jan. 1951, *Proc.* V. 47, p. 398; Feb. 1951, *Proc.* V. 47, p. 485; and Mar. 1951, *Proc.* 47, p. 570.

shown when the deformation in a concrete cylinder is measured with a suitable extensometer. One may argue that structures designed by standard elastic theory have proved to be safe and economical; but it does not follow that they might not have been equally safe and more economical if designed by another theory.

The writer agrees with Hadley that the term "plastic" ought not to be applied to the inelastic deformation of concrete. It is not in accordance with rheological terminology, and it calls to mind the wrong association. Creep occurs in concrete at the lowest loads, and it never attains a magnitude by comparison with which the elastic deformation becomes negligible. In steel, on the other hand, the stress-strain diagram can be divided for all practical purposes into a range where deformation is entirely elastic, and another range where it is entirely plastic. Any attempt to apply indiscriminately to reinforced concrete plastic theories developed to explain behavior of steel structures is therefore bound to lead to erroneous results.

The writer also agrees that a concrete cylinder tested in compression suffers irrepairable damage long before it collapses; but he does not consider this to be a relevant objection to assuming a stress distribution at failure of the type shown in Fig. 1 (d). There is ample evidence to support the view that concrete shows large inelastic deformations prior to collapse if tested carefully at a constant rate of strain.

If plane sections are assumed to remain plane (Fig. 1 (b)), then it follows that stress distribution in a beam immediately prior to collapse is not as shown in Fig. 1 (c), but as in Fig. 1 (d). It is perfectly legitimate to replace the complicated curve of the compressive stress block by a simpler figure, provided it is borne in mind that this is a mathematical device to assist with analysis of more complex problems, and not a representation of a physical fact. The exact shape of the curve is not of fundamental importance,[1] and for flexural members the rectangular stress block adopted by Saliger and Whitney is preferable because it leads to simple equations. It should be emphasized that the replacement of the stress block in Fig. 1 (d) by a rectangle (Fig. 1 (e)) is merely a mathematical device; it is not implied that the distribution is in fact rectangular, as it would be in a plastic material such as mild steel. When Hadley says that "Whitney developed . . . . . a rectangular pattern with stress . . . . of constant value from the outermost fiber to the neutral axis where it abruptly terminated and vanished" he is misinterpreting Whitney's intention.[2] Hadley may find a fifth degree parabola[3] a more convincing shape for the stress block than the rectangle, but the rectangular representation yields a similar result with much simpler mathematics.

The question may be asked whether there is any proof to show that large inelastic strains of the concrete cylinder are obtained

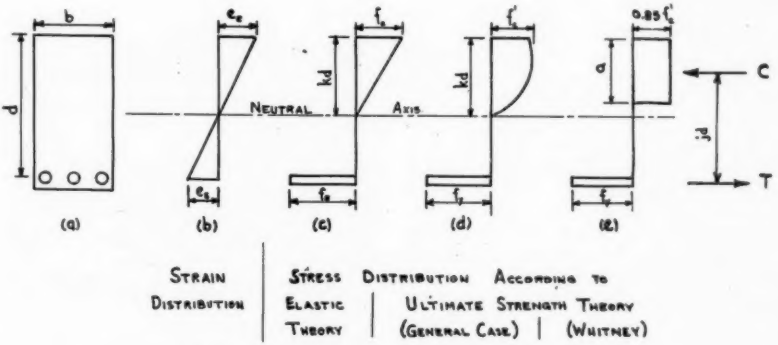


Fig. 1—Stress-strain distribution in concrete beam

in flexure. Strain measurements made on the surface of a concrete beam are apt to be misleading at high loads; but there is more convincing evidence. If the resultant tension and the resultant compression in the beam immediately prior to collapse are equated (Fig. 1 (d))

$$f_y A_s = \int_o^{kd} f_c b dy$$

The steel ratio for balanced design is therefore

$$p_o = A_s/bd = \int_o^{kd} f_c dy/f_y d$$

According to elastic theory, from 1 to 2 percent of tension reinforcement are needed for balanced design using concrete and steel of normal quality. The ultimate strength theory predicts that nearly twice as much steel is required. If therefore a beam with, say, 2.5 percent of tension steel was tested in *pure bending*, it would be over-reinforced according to elastic theory and collapse would occur as a result of primary compression failure in concrete; whereas it would be under-reinforced according to the ultimate strength theory and failure would be due to yielding of tension steel. In the writer's experience such beams invariably fail in tension.

As Hadley himself points out, the agreement between ultimate strength theory and results of beam tests reported by Whitney[3] and R. H. Evans[4] is remarkably close. Elastic and ultimate strength theories differ but little for lightly reinforced sections; but for heavily reinforced sections, and particularly for those containing compression steel, the use of ultimate strength methods leads to a considerable saving in steel, and the use of elastic design appears to be wasteful. This fact is recognized in Section 706 (*b*) of the ACI Code, which allows "the effectiveness of compression reinforcement . . . to be taken at twice the value indicated from calculations assuming a straight-line relation between stress and strain." This rule cannot be justified on the basis of the elastic theory.

There is therefore ample evidence in favor of ultimate strength methods for simply supported beams. The position is less satisfactory when redundant structures are considered. Much attention has been focused recently on plastic theories for design of indeterminate steel structures proposed by J. F. Baker[5] and Van Den Broek.[6] These methods lead to considerable economies in material and to simplifications in design procedure. It would represent a significant advance if they could also be applied to reinforced concrete design. The concept of the "plastic hinge" cannot, however, be transferred to an essentially brittle material such as concrete without searching investigation. Satisfactory evidence must be obtained to show (a) that the structure does not collapse due to excessive disintegration of the concrete at the first hinge before the full number of hinges has formed, and (b) that the frame is not permanently damaged by cracks forming under the action of the working load.

The behavior of single bay portals is currently being investigated at this university. The load which caused the frame in Fig. 2 to collapse was in close agreement with the value obtained from J. F. Baker's theory, and the concrete showed no sign of damage at 40 percent of the ultimate load.* The theory can therefore be applied to this particular portal, using a load factor of 2.5. Judgment must be reserved until satisfactory results have been obtained with a wide range of structures, including frames showing a high degree of redundancy; but the outlook is not without promise.

References

1. Cowan, H. J., *Civil Engineering and Public Works Review*, V. 45, 1950, pp. 376-8, 576-8, 723-5.

*The first crack was observed at 65 percent, and major damage at 80 percent of the ultimate load.

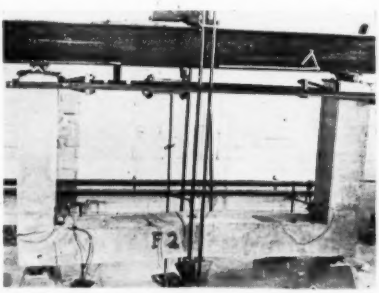


Fig. 2—Portal frame after test. Strain on surface of concrete and reinforcement were measured with electric resistance gages.

2. Whitney, C. S., *Proceedings*, ASCE, V. 66, 1940, pp. 1749-80.

3. Lyse, Inge, *Beton und Eisen*, V. 36, 1937, pp. 124-5.

4. Evans, R. H., *Journal, Institution of Civil Engineers*, V. 21, 1943, pp. 98-121.

5. Baker, J. F., *Journal, Institution of Civil Engineers*, V. 31, 1949, pp. 188-240.

6. Van Den Broek, J. A., *Transactions*, ASCE, V. 105, 1940, pp. 638-661.

HENRY J. COWAN, Dept. of Civil Engineering, University of Sheffield, Sheffield, Eng.

Wanted: Guide in Developing Prestressed Concrete (LR 47-74)*

ACI has already taken the first step in setting up a guide for the development of prestressed concrete—Committee 323, Prestressed Reinforced Concrete, formed in 1942. The committee has subcommittees assigned to review the present knowledge of prestressed concrete, to develop design procedure and to recommend needed research.

The ACI JOURNAL has published several excellent papers on the subject and various ACI members have been active in reporting design theory and developments. Dean Peabody's text gives a good theoretical approach to the subject and Charles C. Zollman has translated Magnel's book on prestressed concrete.

In addition, the Portland Cement Assn. has published reports on prestressed girders and circular tanks, which for the most part were written by ACI members.

The writer has taught a two-hour graduate course on the subject for four years and has drawn heavily on ACI material. During the past two years, there has been more material than can be covered in a two-hour course.

The writer has no objection to a guide, but believes that prestressed concrete will develop safely with what is now available by way of theory and theory reduced to practice in finished European bridges, Walnut Lane bridge, Arroyo Seco bridge and prestressed circular tanks.

It is doubtful if ACI can answer Caughey's questions about patents. Some patents on prestressing are of doubtful validity, but the status of a particular patent will not be known until it has expired or been adjudicated in court. Unfortunately patents on devices used in civil engineering are often not valuable enough moneywise to precipitate a court test and the owner of the patent is more often permitted unchallenged use of it, either personally or through licensing until it expires, than if it were a mechanical device on an automobile. With prestressed concrete "now being considered seriously by American engineers," ways and means of anchoring reinforcement other than those patented will be found if the patent situation acts to retard healthy developments.

T. J. Gut and Charles C. Zollman have developed a method for putting a "header" on the end of each wire which prevents the prestressed wire from pulling through the end plate. This may prove to be a more successful method of anchoring than Magnel's sandwich plates.

Roebling's have developed an excellent high stress wire, although, as yet, relatively few engineers know much about it. Caughey is right when he says most "engineers do not know what kind of steel to specify." But a little investigation on the part of the profession (a letter to John A. Roebling and Sons† or American Steel and Wire Co.‡) will bring the information about high tensile test wire.

It is true that few civil engineers think in terms of steel with high elastic or proportional limit. This difficulty can be corrected by one or two well-written articles on high tension steel.

The talk about "yield strength" and "0.2 percent offset" is unfortunate. The method for finding an approximate elastic limit quickly for commercial testing by offset was developed for soft steels which had a distinct break in the stress-strain curve just after the elastic limit had been reached. In that type of steel the "yield point" or "yield strength," as this approximate elastic limit is called, was but a small percent higher than the real elastic limit given by ASTM definition.

*See also ACI JOURNAL, Mar. 1951, *Proc.* V. 47, p. 561.
†John A. Roebling and Sons, Trenton 2, N. J.
‡American Steel and Wire Co., Rockefeller Building, Cleveland 13, Ohio.

That is not the case with high tensile wire where there is no break-over or sharp knee in the curve. The departure from the straight line or constant relation between stress and strain is gradual and the "yield strength" is as much as 50 percent greater than the real elastic or proportional limit.*

If those who are making and selling high tensile strength wire would quote the elastic or proportional limit rather than the "yield strength" as found by offset method, along with the maximum strength, a closer understanding of what prestress might be used would result—and one hurdle would be, to some extent, eliminated.

F. N. MENEFEE, professor of engineering mechanics, University of Michigan, Ann Arbor, Mich.

Concrete's Etymological Offspring (LR 47-68)†

It was with considerable interest that I noted my memorandum on concrete's etymological offspring had been published in the November issue. It was also with considerable interest that I note three others in the same issue.

Shotcrete.....p. 186
Discrete.....p. 259
Dumpcrete.....p. 19 (News Letter)

In addition to these I have found nine more.

Aerocrete
Aircrete
Colocrete
Dycrete
Plastocrete
Sikacrete
Stonecrete
Strata-Crete
Tamcrete

There are therefore at least 28 examples of this phenomenon, not merely 16 as I once thought.

READER

*Fornerod, M., "Factors in Prestressed Girder Design," ACI JOURNAL, Feb. 1951, *Proc.* V. 47, p. 469.
†See also ACI JOURNAL, Nov. 1950, *Proc.* V. 47, p. 263.

Current Reviews*

of Significant Contributions in Foreign and Domestic Publications

Possibility of saving steel in reinforced concrete frames (in Czech)

K. Hruban and S. Svab, *Transactions of the Dr. E. Benes' Technical University*, Brno (Czechoslovakia), No. 58, 1947

Reviewed by Ivan M. Viest

A study of redistribution of moments in reinforced concrete frames loaded to failure and a report of tests of four single-bent frames. Conclusions are drawn regarding the practical implications of the phenomenon of moment redistribution.

Bricklaying—II

F. William Rau, Delmar Publishers, Inc., Albany, N. Y., 1951, 204 pp. $3.50

A course of study to supplement on-the-job training of apprentice bricklayers. Lesson material and references are provided for trade mathematics and estimating, blueprint reading, trade drawing, details of construction and theory relating to masonry materials, tools, equipment and safety. In each unit a practical work problem is included to demonstrate the application of the subject matter.

Engineering method

John Charles Lounsbury Fish, Stanford University Press, 1950, 186 pp. $3.00

The reader is introduced to logic and reasoning and then by nontechnical illustrations shown their application to engineering thinking as the basis of the "engineering method." Practical considerations are then brought into play and four problems are solved to emphasize their effect. An excellent section discusses uncertainties in engineering work and the manner in which the engineer copes with them.

To the engineering student the book introduces the thinking processes essential to success in his profession and to the practicing engineer it offers an opportunity to re-examine his objectives and methods.

Selection of a preliminary triangular section for gravity dams

G. S. Sarkaria, *Civil Engineering and Public Works Review* (London), V. 46, No. 536, Feb. 1951, pp. 99-101

Reviewed by Charles W. Dohn

Presents a systematic theoretical method for selection of a preliminary gravity section, and includes relevant equations and graphs. A graphic picture is obtainable of the range of factors of safety obtainable with gravity dam sections of reasonable range of proportions and for given standard design conditions.

Boundary problems of cylindrical shells (in Czech)

K. Hruban, *Transactions of the Dr. E. Benes' Technical University*, Brno (Czechoslovakia), No. 78, 1950

Reviewed by Ivan M. Viest

The problems of the effects of boundary conditions on the elastic behavior of cylindrical shells are discussed. An exact solution is given in the first part of the paper. In the second part the author gives a simplified solution, and discusses its adaptation for cylindrical and shallow parabolic shells made of reinforced concrete.

*A part of copyrighted Journal of the American Concrete Institute, V. 22, No. 9, May 1951, *Proceedings* V. 47. Address 18263 W. McNichols Rd., Detroit 19, Mich. Copies of articles or books reviewed are not available through ACI. In most cases they can be obtained direct from the original publishers. Address, when available, will be furnished by ACI on request.

Process for the manufacture of prestressed concrete floor joists

O. J. MASTERMAN, *Civil Engineering and Public Works Review* (London), V. 45, No. 532, Oct. 1950, pp. 641-643
Reviewed by CHARLES W. DOHN

Summarizes the results of trials made to design an inexpensive but suitable mold, and to devise a commercial method of obtaining early high strength in the concrete of prestressed concrete floor joists. Unit molds, application of pressure and vibration and curing in boiling water are part of the method which yields concrete strengths of 5000 psi in four hours.

Concrete quality control—Fallacious application of statistical analysis

L. BOYD MERCER, *Commonwealth Engineer* (Melbourne), V. 38, No. 5, Dec. 1950, pp. 181-188

The author contends that in concrete the materials used and the batching, mixing and testing conditions are so excessively and irregularly variable that accepted mathematical procedures for statistical control have little direct application to concrete production, except in long projects under relatively uniform conditions. In other work, including much major concrete construction, statistical analysis can give a false sense of security with regard to the safety of the structure.

Load-carrying capacity of long reinforced concrete columns (in Czech)

K. HRUBAN, *Transactions of the Dr. E. Benes' Technical University*, Brno (Czechoslovakin), Anniversary Issue, 1949
Reviewed by IVAN M. VIEST

Hruban presents a theoretical study of the load-carrying capacity of both centrically and eccentrically loaded long reinforced concrete columns. The results for the centrically loaded columns are compared with the provisions of the old Czechoslovakian and present Russian, American, British, Swiss and Brazilian specifications. A method is suggested for the design of long eccentrically loaded columns.

Reinforced concrete residential flats at Edinburgh

Concrete and Constructional Engineering (London), V. 46, No. 1, Jan. 1951, pp. 9-13
Reviewed by GLENN MURPHY

Six eight-story reinforced concrete flats are being constructed at Gorgie, Edinburgh. The blocks, 30 ft wide and from 58 to 80 ft long, contain 88 flats. Columns, beams, floors, stairs and balconies are reinforced concrete. The exterior walls, 10 in. thick, consist of 2-in. precast concrete slabs on the outside and a 4½-in. brick wall inside separated by a 3½-in. air space. Partitions are hollow tile. Precast beams are used for the ground floors and precast ribbed slabs 7 in. and 9 in. deep are used for the upper floors. Details of construction are described and several photographs included.

Measurement of the apparent density of an aggregate (Mesure de la densite apparente d'un agregat)

PIERRE DESTABLE, *Annales de L'Institut Technique du Batiment et des Travaux Publics* (Paris), *Essais et Mesures*, No. 18, No. 168, New Series, Jan. 1951
Reviewed by C. P. SIESS

The author is concerned with the problem of determining the density of an aggregate mass of large extent by the usual test method of weighing the amount of aggregate in a container of known volume. He describes new techniques for filling the container and for striking off the top surface. He also investigates the effects of the boundary conditions introduced by the walls of the container and presents a correction for this effect as a function of the ratio of aggregate size to size of the container.

The ABC of concrete (Das Beton—ABC)

A. HUMMEL, Wilhelm Ernst and Sohn (Berlin), 1951, 243 pp. 16 DM
Reviewed by WERNER H. GUMPERTZ

This book is useful for anybody who wants to acquaint himself with German methods of making, handling and testing concrete. While this book makes no claim to theoretical refinement, it is a well conceived treatise on the whole field of concrete. The various properties of concrete and admixtures are treated in some detail, and considerable attention is given to the various types of lightweight concrete. In addition to the Abrams method of designing mixes for certain strengths, several other methods of concrete mix design are discussed. Quality control of concrete is stressed, and the essential rules of making good concrete are well presented in a final summary.

This book is primarily intended for the practical construction man, and as such serves its purpose in an excellent manner.

Ultimate strength of rectangular reinforced concrete beams

HENRY J. COWAN, *Civil Engineering and Public Works Review* (London), V. 45, No. 531, Sept. 1950, pp. 576-578, No. 533, Nov. 1950, pp. 723-725
Reviewed by CHARLES W. DOHN

The author outlines the trapezoidal stress block and the equivalent rectangular stress block theories for balanced design and considers load factor and factor of safety. He then applies the rectangular stress block theory to practical design and draws conclusions. Comparison of formulas derived is made against results of beam tests carried out in the United States and England. These experiments cover a wide range of materials and test conditions and the correlation between the test results and the theory is good. Note is made of the applicability of the stress block theories.

Concrete liquifiers and air-entraining agents (Zur Kenntnis der "Betonverfluessiger" und "Air-Entraining Agents")

H. VIERHELLER, *Zement-Kalk-Gips* (Wiesbaden), V. 3, No. 9, Sept. 1950, pp. 208-209
Reviewed by WERNER H. GUMPERTZ

Author discusses briefly the advances made in the United States in knowledge of air-entraining agents. One of his noteworthy experiments contradicts American experience.

Under closely controlled "optimum" conditions, author succeeded in reducing the water content of his concrete mix by 40 percent using 4 percent of entrained air, in comparison to regular concrete. This air-entraining concrete is stated to have a strength 10 percent higher than that of the original concrete. Author believes that this result gives hopeful indications of further improvements of concrete through controlled use of air-entraining agents.

Reconstruction of Berck light tower in prestressed concrete (in French)

GEORGES TOURRY, *Travaux* (Paris), Dec. 1950

A 115-ft lighthouse at Berck was built of slotted curved precast concrete blocks tied together and to the foundation by vertical prestressing cables. Staggering the ends of these cables at four levels provided continuity in the structure. For further stability, prestressed concrete circular frames, similar to narrow pipe sections, were placed between every third course of precast blocks and tied in with the vertical prestressing. Special blocks anchored cable ends and framed window openings.

Accurate dimensioning of the curved blocks and true size and shape of the circular frames presented some difficulty. The total amount of concrete required for the structure was about ¼ that for normal construction.

Composite concrete and steel construction for continuous beams (La construction mixte ferbeton dans les ouvrages d'art a travees continues)

T. GUERIN and H. PIGEAU, *Annales de L'Institut Technique du Batiment et des Travaux Publics* (Paris), *Theories and Methods of Design* No. 10, New Series No. 157, Nov. 1950
Reviewed by IVAN M. VIEST

The authors describe a new simple method for building continuous concrete and steel composite beams, which prevents cracking of the concrete slab in the negative moment region by prestressing the portions above the supports. The slab is prestressed by lowering the intermediate supports. The theoretical basis is explained and examples of three railroad bridges are given and compared with similar structures built by conventional methods. The theoretical calculations are compared with the results of measurements made on the railroad bridges.

Vibrated mass concrete

J. FRITSCH, *Civil Engineering and Public Works Review* (London), V. 46, No. 535, Jan. 1951, pp. 30-32 and V. 46, No. 536, Feb. 1951, pp. 102-104
Reviewed by CHARLES W. DOHN

Comments on cement content, the strength of lean mixes and sources of error in production and testing; deals with the principles of concrete strength; introduces and discusses production of mass concrete of uniform properties; and presents a summary and conclusions.

Increased factor of safety of the method of production depends on continuous working with a uniform water-cement ratio and uniform degree of compaction. Quantity of cement paste should be varied rather than amount of water. A new concept is introduced with regard to measuring compaction called "response to vibration." The general method of specifying a certain quantity of cement per unit volume of concrete necessitates a method of manufacture producing unallowable variation and great uncertainty in the quality of concrete.

Cracks in concrete due to properties of cement (Rissebildung im Beton in Abhangigkeit vom Zement)

W. CZERNIN, *Zement-Kalk-Gips* (Wiesbaden), V. 4, No. 1, Jan. 1951, pp. 13-14
Reviewed by WERNER H. GUMPERTZ

This article deals substantially with a book by R. Dittrich on the relationship (if any) between cement composition and pavement cracks made with that cement. Dittrich claims that a tendency of the concrete to crack can be indicated by the empirical formula

$$k = \frac{\text{percent } MgO \times \text{percent } Al_2O_3}{\sqrt[3]{\text{percent } R(4900)}}$$

where $R(4900)$ is the fineness of the cement used. Author concludes from his own experiments on best sections of the German *Autobahn* system that it is not possible to draw any significant conclusions from cement composition on the tendency of the pavement to develop cracks. Dittrich suggests further study of this question in a succeeding rebuttal.

Reconstruction of a quay at Wallsend

Concrete and Constructional Engineering (London), V. 45, No. 12, Dec. 1950, pp. 435-442
Reviewed by GLENN MURPHY

A 642-ft quay on the north bank of the river at Wallsend-on-Tyne has been reconstructed and extended. The deck of the extensions is supported on vertical reinforced concrete piles with an 18-ft spacing. All construction below high water is of precast reinforced concrete. The deck consists of a pair of longitudinal main beams which carry the crane rails, two smaller longitudinal beams for standard-gage rail track and transverse beams. The design load was 672 psf, in addition to the crane locomotive and berthing loads. The 60-ft piles are 16 in. square and carry working loads up to 54 tons. Design stresses of 18,000 psi in the steel and 750 psi in the concrete were used. Concrete test cubes exceeded the specified strength of 1400 psi at 14 days. Construction details and a number of excellent photographs are included.

Electrical treatment of concrete in cold weather

P. HALLER, *Civil Engineering and Public Works Review* (London), V. 45, No. 532, Oct. 1950, pp. 651-653
Reviewed by CHARLES W. DOHN

This article describes a method of controlling the temperature of setting concrete by the flow of an electric current through it. The fact that electrical resistance of concrete increases as it sets aids progressive set, resistance being a minimum at initial set. Formulas are presented for calculating initial set resistance of any concrete of known mix. A high water content increases the electrical conductivity.

Further formulas are developed for calculating quantity of heat due to chemical process during setting and the quantity of heat due to passing of the current as well as residual and lost heat.

Alternating current is used and several practical types of electrodes are described including flat plates and reinforcement heating. Precautions must be taken to limit water evaporation and extra covering should be used on thin sections.

Tests of a tilting-drum concrete mixer (Essais de betonniere a tambour basculant)

ALBERT JOISEL, *Annales de L'Institut Technique du Batiment ot des Travaux Publics* (Paris), *Materiel du Chantier* No. 5, No. 169, New Series, Jan. 1951
Reviewed by C. P. SIESS

Tests were made on a small laboratory-type tilting-drum concrete mixer having a diameter of about 19 in. and a total volume of about 2 cu ft. The effects of a number of variables on the homogeneity of the concrete were investigated. The criterion of homogeneity was the dispersion of the unit weights of samples taken from various portions of the batch. Various mixes were used.

Variables in the mixer itself included: the angle of inclination of the axis, three blade designs with height and shape as the variable, the angle between the blade and the axis of rotation of the mixer, and the speed of rotation of the mixer between limits of 16-57 rpm.

Variables in operation included: size of batch, order of charging the various constituents, charging with mixer at rest or in motion, and time of mixing.

Analysis of cylindrical tubes of variable thickness subjected to circular bending (Calcul des tubes cylindriques de revolution d epaisseur variable, sollicites a la flexion circulaire)

JAQCUES PASCHOUD, *Bulletin Technique de la Suisse Romande* (Lausanne), V. 77, No. 2, Jan. 27, 1951, pp. 13-20
Reviewed by J. EDMUND FITZGERALD

The calculation of deformations and stresses in a cylindrical tube of variable thickness

subjected to moments distributed around the end circumference is treated. Previous methods proposed by Flugge, Dumas, Tache and the author led to much more complicated and lengthy calculations than in the special case of a tube of constant thickness.

The present work makes possible the calculation of cylindrical tubes of variable thickness with the same degree of ease as tubes of constant thickness. The mathematical justification of the method is also included.

The method is explained briefly and illustrated by some numerical examples. Design charts are included.

Concrete ship repair slipways at Newcastle

O. D. Floyd and W. S. Butcher, *Commonwealth Engineer* (Melbourne), V. 38, No. 7, Feb. 1, 1951, pp. 268-275

Two concrete slipways for small ships consisted of reinforced concrete beams on timber piles. Both the 627-ft, 1250-ton slipway and the 390-ft, 300-ton structure are built on a grade of 1 in 15.

A dense impermeable concrete, to resist the action of sea water, was placed in steel forms. The coarse aggregate was ¾-in. maximum size blast furnace slag; sand from the site was used as fine aggregate. For reinforced sections, a 1:2:3 mix requiring 6.9 bags of cement per cu yd was used, while for retaining walls and mass concrete the mix was 1:4:5 containing 4.1 bags of cement per cu yd.

For portions of the site containing acid ground water, low heat cement was specified with a W/C of 0.55. Sisalkraft was placed under members placed in this section and other surfaces in contact with ground water were painted with bitumen emulsion.

Construction of a natural draft cooling tower at Portarlington

Bulletin, The Institution of Civil Engineers of Ireland (Dublin), No. 2, Mar. 1951, *Trans.* V. 77, pp. 47-57

To cool 1,800,000 gal. of condensing water per hour for the turf-fired boilers at Portarlington power station a hyperbolic reinforced concrete cooling tower 236 ft high was built. Resting on a 9-ft circumferential slab 9 in. thick the tower is 175 ft 4 in. in diameter at the base, 89 ft 8 in. at the neck and 97 ft 2 in. inside at the top. The double curvature required extensive scaffolding and careful forming. The 4 to 5-in. slump concrete was placed in 66 lifts over a period of 11 months. Test cubes averaged 5500 psi at 28 days.

The cooling stack inside the tower required 10,000 concrete bearers, posts, struts and braces and an equal number of small filling pieces precast on the job. Reinforcement was electrically welded and concrete was vibrated in the molds. The concrete contained 700 lb of cement per cu yd, ½-in. maximum size aggregate and had a W/C of 0.40.

Buildings of fabric-like reinforced concrete (in Hungarian)

B. Samsondi-Kiss and T. Farkas, *Epites-Epiteszet* (Budapest), V. 2, No. 6, June 1950, pp. 402-405
Hungarian Technical Abstracts No. 3, 1951

Originally intended for ceilings in multistory buildings this method, with suitable modifications, may be used for prefabricated supporting structures of houses. The construction consists of a reinforced concrete grate, which can be so closely spaced as to resemble woven fabric.

The manufacturing process is similar to gravity die casting in foundries. The model of the grate is prepared from metal or other solid material and pressed into a plastic mixture of clay and powdered charcoal. The mold thus formed is fitted with reinforcing steel and filled with a thin concrete mortar. In other methods metal molds are used or a lining of hygroscopic material is applied to the mold and remains as the finished surface of wall or ceiling.

Buildings erected from these prefabricated units are extremely light in weight. Constructional units and their assembly are illustrated.

The Holter system

Roads and Road Construction, V. 28, No. 331, July 1950
Highway Research Abstracts Feb. 1951

In the Holter system of concrete pavement construction used in Norway a mortar of cement, sand and water is spread on the subgrade in a uniform layer. On this the desired amount of gravel or broken stone is placed. Sheepsfoot rollers then force the coarse aggregate into the mortar which at the same time works upward. After 20 minutes of this mixing, the slab is compressed and evened

by a heavy smooth roller. Diagonal and transverse tampers compact the concrete and surface finish is imparted by a smoothing template.

Advantages of this system are said to be:

1. A substantial part of the coarse aggregate remains on top of the pavement, thus giving a more homogeneous and enduring surface.

2. Reduced construction time. Pavement may be opened to traffic a day or two after completion.

3. About 20 percent lower construction costs compared with most other methods now in use.

Modern trends in arch dam construction and design

CHARLES JAEGER, *Civil Engineering and Public Works Review* (London), No. 526 to 531, Apr. to Sept. 1950, Parts 1 to 6

Reviewed by CHARLES W. DOHN

Gives information on many high thin arch dams and cupola arch dams. Outlines the Italian method of cupola dam analysis and draws provisional conclusions on Italian practice. Considers a proposal for a method of reference for arch dam calculation and deals with rock elasticity and plasticity. Considers conditions at the abutments and their shape together with the ultimate crushing strength of an arch dam and summarizes the conclusions reached in the previous parts of the article. Mention is made of some extremely high thin arch dams which are among the boldest engineering projects ever undertaken.

The articles are well written and particularly well illustrated with numerous fine drawings and photographs. Extensive bibliographies are given at the end of each part. Extremely high factors of safety can be obtained with thin arch dams and a value of 12 is mentioned. No gravity dam or buttress dam can attain such high safety factors or equal the economy of an arch dam where geology permits an arch dam.

Essential factors for adequate curing

WILLIAM J. SHORE, *Rock Products*, V. 54, No. 2, Feb. 1951, pp. 154-155 and 160

Reviewed by DONALD M. AGRIMSON

The author is of the opinion that there is room for improvement in almost every block plant. Failure to produce well-cured blocks is due mainly to lack of attention to minor details essential in block manufacturing. Steam curing is frequently conducted improperly because the block maker has attempted to improvise a steam-curing system—a practice that seldom produces satisfactory results.

In designing a good steam-curing system the following factors are considered:

(a) Hourly block production

(b) Number of hours operated per day

(c) Type racks, pallets and tiers of blocks per rack

(d) Number of curing kiln compartments needed

(e) Size of same, method of construction, doors, etc.

(f) Selection of steam generating equipment

(g) Type of fuel to be used and method of firing

(h) Piping from boiler to kilns and method of steam control

(i) Temperature recording and indicating apparatus

(j) Exhaust system for cooling block

Flat slab floors without capitals (Les planchers-dalles sans champignons)

A. BALENCY-BEARN, R. DEVARS DU MAYNE, M. TURIN, M. HAHN and J. CHEFDEVILLE, *Annales de L'Institut Technique du Batiment et des Travaux Publics* (Paris), *Beton, Beton Arme*, No. 16, No. 167, New Series, Jan. 1951

Reviewed by C. P. SIESS

The question of flat-slab floors without capitals is discussed by several writers from several points of view. One section is devoted to methods of computing moments, including exact and approximate mathematical methods as well as semi-empirical methods such as those of the ACI Code. Moments obtained by several methods are compared. A second section contains descriptions of various structures having this type of floor. Examples from both American and French practice are given. Rather meager results of load tests on two buildings are reported. In one case four panels were loaded and deflections measured; in the other, only one panel—an edge panel—was loaded, and strains as well as deflections were measured. Laboratory tests were made on two models to investigate the effectiveness of the slab in resisting shear around the column head. One of these test specimens was reinforced only with ordinary

bars and vertical stirrups; the other was provided with shear reinforcement in the form of rolled-steel channels. Strains and deflections were measured in these tests.

Concrete pavements (Betonverhardingen)

F. KANSTEIN, *Cement* (Amsterdam), No. 1-2, 1951, pp. 23-27

Reviewed by J. W. T. VAN ERP

Oldest concrete highway pavements in the Netherlands are 25 years old and still in good repair without too much upkeep, vouching for the soundness of that type of highway construction. Latest additions to the network of concrete roads have lanes 10 ft wide for slow traffic and 11 ft wide for fast traffic (middle lanes). Transverse expansion joints are 75 ft apart. Under the lateral joints, 4 ft wide supporting slabs are placed. The usual 2 ft long dowels across these joints are being abandoned. These dowels, especially if not meticulously placed, are a frequent cause of trouble. Therefore, lateral support slabs have been adopted and are more economical.

Pavement slabs are 7 in. in the middle increasing to 9 in. at the edges. The lower ⅔ of the 7-in. concrete slab is a sub-slab with a cement content of 5½ bags of cement per cu yd and the upper ⅓ is concrete finish with a cement content of 7 bags of cement per cu yd.

In the Utrecht-Arnhem stretch, described in this article, the subsoil was sand. The concrete was placed on a layer of waterproof building paper to insure moisture retention. No reinforcement was used except for the dowels in the longitudinal construction joint between lanes. The completed 6½ miles of 21-ft wide road cost $345,000 including all viaducts, built to accommodate the future double width.

Influence of fineness on initial and ultimate strength of portland cement (Der Einfluss der Feinheit auf die Anfangsund Endfestigkeiten von Portland-Zement)

W. GRUENDER and S. TABBAH, *Zement-Kalk-Gips* (Wiesbaden), V. 3, No. 4, Apr. 1950, pp. 67-71

Reviewed by WERNER H. GUMPERTZ

Authors make reference to work by Kuehl, Helbig, Eiger, Guye, Kavcic, Anderegg and Hubbell on cement strength in relation to its fineness. Experiments reported were made with gypsum cement of different fineness on usual bending and compression specimens 3, 7, 28, 56 and 112 days old. Specimens were prepared in accordance with German standards DIN 1164.

Results of the experiments are summarized:

1. After mixing cement with water, the cement particles are initially covered with a gel which hardens until complete hydration has taken place. At this time, optimum strength has been obtained.

2. Grinding cement finer does not influence its optimum strength, but only its initial strength.

3. Increase in strength is initially at a fast rate which decreases as ultimate strength is approached.

4. The initial bending strength rises sharply with an increase in specific surface of the cement.

5. The speed with which the bending strength reaches its optimum value is proportional to the fineness of the cement.

6. Compressive strength increases considerably as the fineness of the cement increases; but it requires more aging to reach its optimum value.

7. The adding of ultrafine cement to a normal cement does not increase its ultimate strength.

The reviewer calls attention to the fact that this paper deals only with strength properties of finely ground cement.

Report preparation

FRANK KEREKES and ROBLEY WINFREY, Iowa State College Press, Ames, Ia., 1951, 450 pp. $6.90

Prepared for both engineering students and practicing engineers who are called upon to prepare reports, this second edition on report preparation has been enlarged and improved.

Each element involved in producing an engineering report is described and categorized and the preparation process outlined. Samples of all parts of a report, including letters and questionnaires used in securing data, are presented in facsimile form.

New sections added include one on magazine feature articles and technical papers and another on letters of application and job interview data. The section on editing, copyreading and proofreading has been enlarged

and the list of references in the appendix has been doubled. An index was also added to make the manual more valuable as a reference book.

The extensive illustrative examples are an outstanding feature of the book; its letter-size pages facilitate reproduction at full size of most of the elements treated.

The various sections include a general treatment of reports, planning and investigation, collection of information, mechanics of style, format and arrangement, tabular presentation, illustrations and effective writing. Other sections cover writing the first draft and revising, correspondence, letter reports and short reports, formal reports, magazine articles and technical papers, oral presentation, letter of application, and editing, copyreading and proofreading. The appendix includes two complete formal engineering reports.

The book should prove helpful to anyone preparing engineering reports. Sections of the book, including correspondence examples, will also be of value to secretaries and typists who assemble and copy reports for engineering offices.